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HELVITE AND DANALITE FROM NEW MEXICO AND THE HELVITE GROUP*

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ABSTRACT

Helvite and danalite occur at Iron Mountain in Sierra and Socorro Counties, southwestern New Mexico, in a metamorphic contact zone between Paleozoic limestone and Tertiary rhyolites and granites. The host rock is a dark, banded tactite composed chiefly of magnetite, fluorite, chlorite, and diopside. The most coarsely crystallized helvite at Iron Mountain is amber to mahogany colored. $G = 3.334$, $n = 1.746$.

Danalite and some of the finely disseminated helvite occur in a conspicuously banded, light grayish-green tactite that has been termed "ribbon rock." Danalite is pale honey-yellow and resembles a beryllium-bearing grossularite with which it is in places intergrown. The index of refraction ranges from 1.750 to 1.759. Associated beryllium-bearing minerals are grossularite, idocrase, pink epidotes, tilleyite, and thuringite.

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** Mineralogical work by Glass; geology by Jahns; analytical chemical work by Stevens.

A staining method for distinguishing the members of the helvite group from the garnets is given.

The helvite group consists of three isomorphous species: helvite, $\text{Mn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$; danalite $\text{Fe}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$; and genthelvite, $\text{Zn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$. The name genthelvite is here given to the zinc member in honor of the memory of Frederick A. Genth who first described this species in 1892. The only known occurrence is West Cheyenne Cañon, El Paso County, Colorado. Genthelvite is isometric, tetrahedral. Pale rose-red. $G=3.66$, $n=1.744$.

Analyses of members of the helvite group are assembled, together with determined indices of refraction for all available material. Correlation of variations in specific gravities and indices of refraction with chemical composition is shown on a three component diagram. Measured values of a_0 are given.

The properties of the three end members are:

		G	n	a_0
Helvite	$\text{Mn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$	3.20	1.728	8.27
Danalite	$\text{Fe}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$	3.35	1.771	8.18
Genthelvite	$\text{Zn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$	3.70	1.740	8.10

INTRODUCTION

The contact deposits of iron and other metals on Iron Mountain in the northern Sierra Cuchillo, southwestern New Mexico, have been known and repeatedly examined by prospectors for many years. The presence there of several unusual minerals was first noted in 1926 by T. C. Parker, at that time principal claim owner in the area, but it was not until November 1941, when L. W. Strock (30) announced his discovery of beryllium in certain of the ores, and his identification of the chief beryllium-bearing mineral as helvite, that the attention of the geologists was focused upon these deposits. A detailed examination of the district was made by the Geological Survey during the summer and fall of 1942, and the more significant minerals have been studied in the laboratory.

OCCURRENCE

Iron Mountain is a high ridge that forms the north end of the Sierra Cuchillo in Sierra and Socorro Counties, New Mexico (Fig. 1). It is located nine miles north of Winston (Fairview), the nearest town, and 33 miles northwest of Hot Springs, from which it can be reached over a fair gravel road (State Route 52).

The mountain, which is elongate north and south, is a narrow, tilted fault block, and the faceted spurs along its western base are conspicuous features. It consists of Paleozoic limestone and associated minor sandy and shaly beds that dip rather uniformly east at moderate angles. These sedimentary rocks have been cut by many dikes and irregular plugs of rhyolite and coarsely porphyritic rhyolite, and by younger sills and dikes of aplite and fine-grained granite, all of which are believed to be of

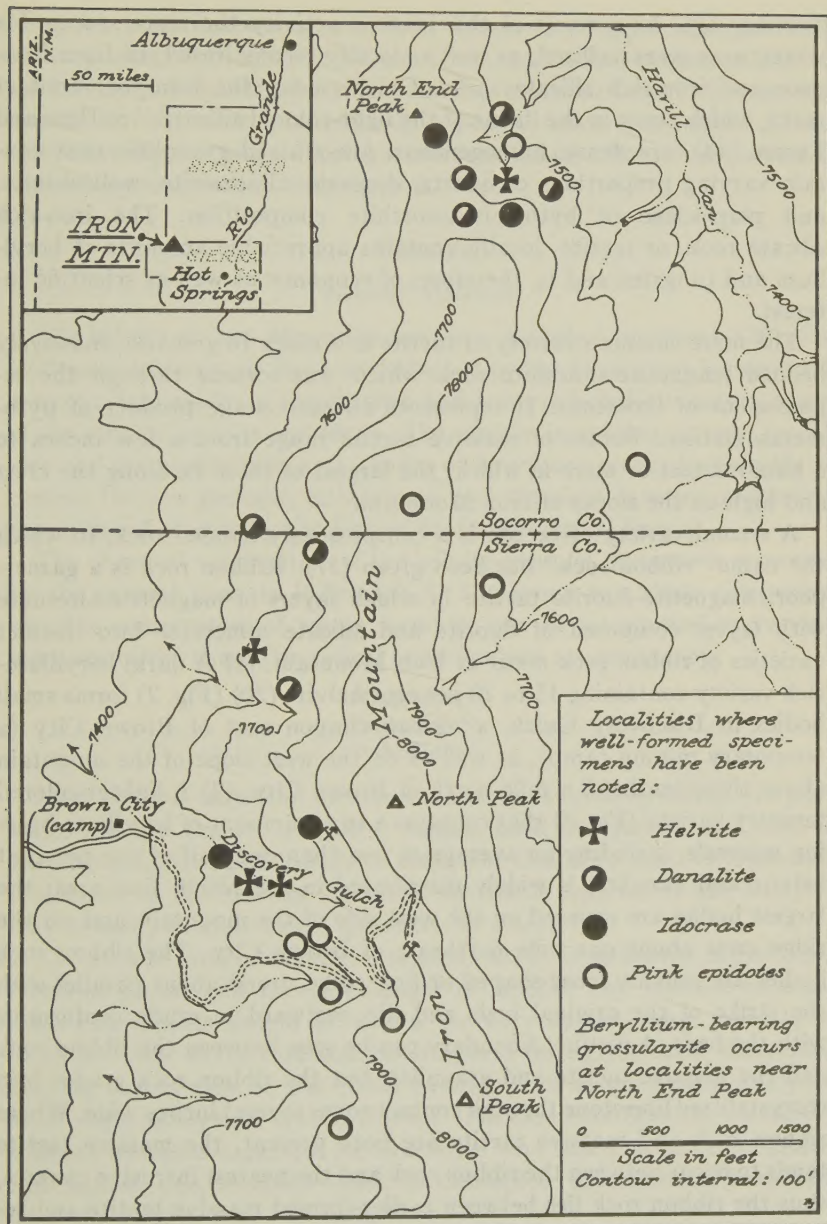


FIG. 1. Topographic map of Iron Mountain, showing localities from which well-formed specimens of helvite, danalite, idocrase, and pink epidotes have been obtained. Inset shows location of Iron Mountain in Sierra and Socorro Counties, southwestern New Mexico.

Tertiary age. As a result of this igneous activity the more susceptible strata were recrystallized, as well as locally reconstituted, to form iron-poor and iron-rich silicate rocks. Chief among the iron-poor contact rocks, which occur in the "zone of the light-colored silicates" of Hess and Larsen (14), are dense, homogeneous, fine-grained granulites that contain varying proportions of quartz, diopside, clinozoisite, wollastonite, and plagioclase of bytownite-anorthite composition. The iron-rich silicate rock, or tactite, locally contains appreciable amounts of beryllium and tungsten and is, therefore, of economic as well as scientific interest.

The more common variety of tactite is a black to greenish, massively bedded magnetite-andradite rock which was formed through the replacement of limestone. It represents an early-stage product of pyrometasomatism. Bodies of massive tactite range from a few inches to a hundred feet or more in width; the largest of these lie along the crest and high on the slopes of Iron Mountain.

A second variety of tactite is a conspicuously banded rock, to which the name "ribbon rock" has been given (17). Ribbon rock is a garnet-poor, magnetite-fluorite tactite in which layers of magnetite alternate with layers composed of fluorite and silicate minerals. Two distinct varieties of ribbon rock occur at Iron Mountain. (1) A dark, beryllium-rich variety containing 15 to 20 per cent helvite (30) (Fig. 2) forms small bodies in Discovery Gulch, a narrow canyon east of Brown City (a temporary mining camp), as well as on the west slope of the mountain about three-tenths of a mile north of Brown City. (2) A lighter-colored tapestry variety (Fig. 3) that contains a small amount of beryllium-bearing minerals, including an average of less than one-half of one per cent helvite and danalite, is widely distributed in the North End area; the largest bodies are exposed on the west side of the mountain and on the ridge crest about one mile northeast of Brown City. The ribbon rock bodies are roughly lense-shaped or finger-like, trend about parallel with the strike of the original beds and dip eastward in crude conformity with the beds. A distinct boundary can be seen between the ribbon rock and the massive tactite and granulite, but the ribbon rock grades into recrystallized limestone through contact zones several inches wide. Where ribbon rock and massive tactite are both present, the massive tactite tends to occur between the ribbon rock and the nearest intrusive contact, thus the ribbon rock lies between earlier-formed massive tactite and recrystallized limestone. It appears to be a product of late-stage hydrothermal action.

Immediately following, and perhaps in part contemporaneous with the action of ordinary silication, hydrothermal solutions penetrating

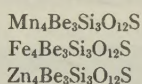
along fractures introduced abundant fluorine and appreciable amounts of manganese, iron, zinc, beryllium, boron, and other elements. Most of the helvite and danalite, beryllium-bearing grossularite and idocrase, and members of the pink epidote group appear to have been formed during this relatively late stage. During a still later stage, other minerals such as chalcedony and zeolites were formed.

HELVITE

General Statement

The helvite at Iron Mountain has been described by Strock (30), but additional information has been obtained by the Geological Survey from a recent field study of the district and from detailed laboratory study of the mineral and its associates. The rapidly increasing interest in helvite and its possibilities as a source of beryllium make it advisable to present the new geologic, mineralogic, and chemical data secured during the course of studies by the United States Geological Survey.

The chemical composition of the helvite group of minerals is expressed by the general formula $R_4Be_3Si_3O_{12}S$. The group is a three component one, the composition of whose members can be interpreted as varying mixtures of the three theoretical end-members or components



None of these three end members is known to occur in nature in a pure state. All the known members contain both manganese and iron in varying quantities and in half of them zinc also is present. It is possible that many of the helvites for which no zinc is reported in the analyses may actually contain small quantities of zinc.

The atomic ratio of beryllium remains fixed, as indicated in the three formulas given, and the percentages of BeO in any mixture of these three components should lie within the very narrow range from 12.58 to 13.52. That the actual analytical figures transgress these theoretical limiting values may be due either to impurities in the sample analyzed or to slight analytical errors. Bowley (2) comments that the numerous complex formulas suggested for this series "are based on incorrect analytical figures, due, in many cases, to incomplete separation of beryllium from manganese, iron, and zinc."

In consequence of the varying quantities of Mn, Fe, and Zn, the physical properties of members of the group vary with the chemical composition. The determined specific gravities of members of the helvite group range from 3.16 to 3.66 and the determined indices of refraction from

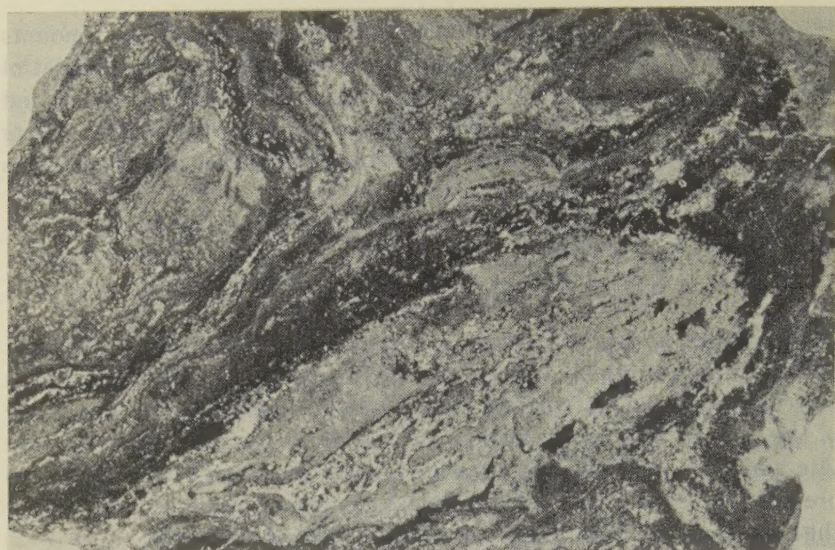


FIG. 2. Dark, beryllium-bearing ribbon rock tactite from Discovery Gulch, Iron Mountain, New Mexico. Black areas are fine-grained silicates stained with manganese oxide; gray areas are magnetite; grayish, irregular pod-like areas are helvite; and the white patches and thin veinlets are fluorite. (Natural size.)

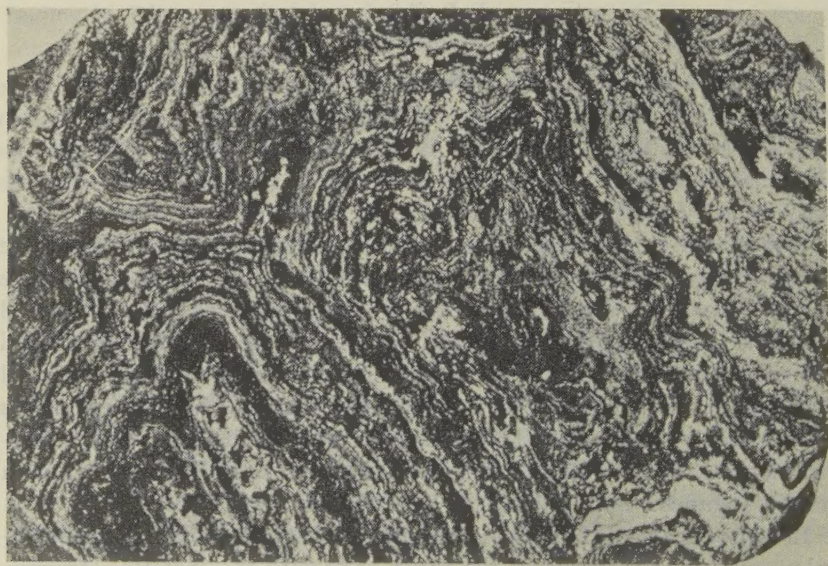


FIG. 3. Ribbon rock tactite from North End area, Iron Mountain, New Mexico. White veinlets and vug fillings are fluorite in which is embedded small crystals of helvite and beryllium-bearing grossularite. Gray ground-mass is an intimate intergrowth of magnetite, fluorite and silicates. (Natural size.)

1.728 to 1.765, a value probably too high. In the last part of this paper an attempt is made to correlate the varying specific gravities and indices of refraction with chemical composition for all known members of the helvite group.

Discovery Gulch Deposits

Most of the known coarsely crystalline helvite (Fig. 2) occurs at Discovery Gulch in small bodies of tactite along a contact between recrystallized limestone and a plug of coarsely porphyritic rhyolite. Smaller amounts have been found in tactite lenses that lie in recrystallized limestone at and near contacts with masses of aplite and fine-grained granite. The iron-rich host rock for the helvite (Fig. 2) is composed rather uniformly of magnetite and fluorite, with minor amounts of biotite, chlorite, and diopside. Garnet is rare to absent. The tactite is characteristically layered, with crenulated parallel laminae that locally are concentric about aggregates of solid magnetite or more commonly crystalline fluorite. These bands range in width from 0.05 mm. to 10 mm., with a prevailing average of about 0.2 mm. Some consist of solid helvite, but most helvite-bearing layers are aggregates of fluorite and helvite; the intervening layers are solid magnetite or biotite-chlorite aggregates 3 to 10 mm. thick. Irregular pods of coarsely crystallized helvite, with maximum dimensions of 1 inch by 3 inches by 4 inches, are present but are not common. Although helvite locally constitutes as much as half the rock, it is generally present in much smaller quantities, even in the richest ore shoots.

North End Deposits

A small quantity of helvite from the Lower Star body, North End area, has an index of refraction (1.737) lower than that of the more typical and more abundant helvite from Discovery Gulch, and indicates a higher manganese and lower iron-plus-zinc content. These lower index grains were found in crushed material and their association is not known.

Properties

The helvite from Discovery Gulch is amber-brown to mahogany-red (Ridgway's Color Standard) with a vitreous to resinous luster. Much of it is stained dark brown or nearly black by iron and manganese oxides. Most of the helvite is massive, but well-formed crystals occur in vugs, commonly associated with comb quartz and fluorite. Simple tetrahedra though not rare are less common than the combination of positive and negative tetrahedra. On many crystals the positive and negative faces are so equally developed that perfect octahedra have resulted. Although most of the crystals are less than 4 mm. in diameter, some reach dimen-

sions as great as 12 mm. ($\frac{1}{2}$ inch) on an edge. Fine and evenly spaced striations appear on some of the crystal faces. The mineral has a hardness of about 6, but because of its brittleness it appears to be much softer. Cleavage is absent or at most very poorly developed. The helvite from Discovery Gulch deposit seems to be uniform and constant in composition and properties. The specific gravity of the analyzed sample is 3.334, and its index of refraction is 1.746 for sodium light. By contrast the minerals of the helvite group from the North End deposits vary considerably in their indices.

Helvite resembles garnet, and it is possible that this beryllium-bearing mineral has been overlooked or mistaken for garnet in other contact metamorphic deposits. The chief properties that distinguish helvite from the typical andradite garnet of the Iron Mountain area are its tetrahedral habit, hardness of only 6, and lower specific gravity. The associated andradite is liver-brown to greenish-yellow or pale canary-yellow, shows

TABLE 1. ANALYSIS OF HELVITE FROM DISCOVERY GULCH, IRON MOUNTAIN, SOCORRO AND SIERRA COUNTIES, NEW MEXICO
Rollin E. Stevens, analyst

	Analysis	Atomic Ratios	
SiO ₂	31.54	.5251	
Al ₂ O ₃	.37	.0073	
		.5324	3.00 Si ₃
BeO	13.60	.5436	3.06 Be ₃
MnO	26.51	.3738	
FeO	18.02	.2508	
ZnO	5.61	.0689	
CaO	1.62 ¹	.0289	
MgO	None		
		.7224	4.07 (Mn, Fe, Zn) ₄
S	5.34	.1665	.94 S
TiO ₂	.01		
H ₂ O	.06		
	102.68		
Less O=S	2.67		
	100.01		

Formula: (Mn, Fe, Zn)₄Be₃Si₃O₁₂S

¹ The unusually high calcium content is due partly to the presence of a few fragments of fluorite.

abnormal double refraction, and has an index of refraction ranging from 1.865 to 1.885. Helvite dissolves slowly in boiling hydrochloric acid (1:1), forming a silica gel and hydrogen sulfide, whereas garnet is very difficultly soluble in acid and neither gelatinizes nor yields hydrogen sulfide.

The most coarsely crystallized and most highly concentrated mahogany red type of helvite from an exploration pit in Discovery Gulch was analyzed. The rock from which the mineral was taken is a magnetite-rich tactite composed of $68\frac{1}{2}\%$ magnetite, 18% fluorite, and $13\frac{1}{2}\%$ helvite.

The sample was carefully prepared, first by crushing and screening to remove the fine powder, then by removing the magnetite with a magnet and the fluorite with heavy solutions, and last by carefully hand picking only the grains with bright luster.

DANALITE

North End Deposits

The danalite from the North End Deposits occurs chiefly in the ribbon rock (Fig. 3) that lies relatively low on the west slope (Fig. 1) of the north end of Iron Mountain. This ribbon rock, composed essentially of magnetite, fluorite, biotite, and chlorite, has a reddish or a dark green groundmass with white to pale yellow bands 0.1 mm. to 3 or 4 mm. wide, which are either straight or curved but generally arranged concentrically about cores filled with aggregates of fluorite crystals. The banding may be ascribed to a diffusion effect, involving solutions that worked outward from fractures and "open" bedding planes. In places the thicker layers and fluorite-filled vugs contain scattered crystals of danalite. The ribbon rock bears a remarkable resemblance in structure and in composition to the orbicular contact rock of Brooks Mountain, Seward Peninsula, Alaska, described by Knopf (18).

Properties

The danalite is pale creamy yellow to honey-yellow. The crystals show rounded dodecahedral form and are embedded in fluorite aggregates, commonly in intimate association with grossularite from which it is not readily distinguishable. Under the microscope both danalite and the associated grossularite show optical anomalies. The index of refraction of the danalite is variable, ranging from 1.750 to 1.759, a little lower than that for the grossularite, which also has variable index, 1.765 to 1.775.

It was not possible to obtain enough of this danalite for chemical analysis but its relatively high index of refraction shows that it must be high in

iron and close to the iron end component, as spectrographic tests show that zinc is absent.

The relations between the danalite and grossularite in the North End ribbon rock seriously complicate field identification, because these two minerals not only look alike, but, unlike the widely separated andradite and helvite at Discovery Gulch, they commonly occur together. The dodecahedral habit of the crystals is the same for both minerals, with occasionally less distinct faces on the danalite. Both minerals have the same color. Some of the crystals of grossularite have a brilliant luster, but not all of it is transparent and glossy; much of it is translucent and brittle like the danalite.

Distinctions between the two minerals may be made with a petrographic microscope by immersing the grains in a liquid of index 1.760; grains of lower index are danalite and grains of higher index are grossularite. The distinction may also be made by means of a staining method. A lump of the rock or a polished surface cut parallel to the vein where flat aggregates of crystals are exposed may be used. Staining of the smoothly polished surfaces of specimens will clearly show the relation of the danalite to the grossularite. Examples of what appeared to be complete or nearly complete replacement of grossularite by danalite have been noted in several specimens. If replacement has actually taken place the dodecahedral form of the grossularite may have been inherited by the danalite.

STAINING METHOD FOR DISTINGUISHING MEMBERS OF THE HELVITE GROUP FROM THE GARNETS

A successful staining method for the identification of the helvite group has been developed by John W. Gruner at the laboratories of the University of Minnesota for Continental Machines, Inc., Minneapolis, Minnesota, who own claims at Iron Mountain, New Mexico. We quote from their report:

"The mineral resembles garnet in several respects and can be easily confused with it especially in small grains and in those of microscopic size. Since garnet is a very common constituent in the rocks of this area (Iron Mountain, New Mexico), it becomes quite difficult to judge a sample of ore as to its possible or probable content of beryllium. The difficulty is increased by the fact that chemical analyses for beryllium are long and tedious if any accuracy is desired.

"For practical purposes of finding ore, it should not be necessary to analyze for beryllium chemically, except for checking results. If the grains of helvite can be made visible easily, either to the naked eye or under the microscope, they can be counted and their ratio to the number of grains of the gangue determined.

"Such a method has been developed and checked by literally hundreds of tests and many chemical analyses. It is quick and simple and absolutely foolproof. A very small

representative sample of the powdered or crushed rock is put in a small 50 cc. glass beaker and enough dilute H_2SO_4 (one acid to five water) is added to cover the sample. A pinch of arsenic trioxide (As_2O_3) is added, and the solution is boiled for about one to two minutes. The acid is then decanted and the powder is washed with water a couple of times by decanting. The contents of the beaker still covered by a little water are examined under the binocular microscope. Any helvite present will be stained a brilliant canary yellow. This stain is arsenic sulfide (As_2S_3). This test is so sensitive that one grain of helvite can be found among thousands of gangue minerals. Should it happen that the gangue were all yellow garnet, the canary yellow could still be spotted. If there were any doubt, *metallic* antimony could be *substituted* for the arsenic trioxide in test above. A brilliant red would stain the helvite then. This stain is antimony sulfide (Sb_2S_3)."

ASSOCIATED MINERALS

The tactite zones at Iron Mountain have yielded more than fifty mineral species. Only those minerals that show beryllium in traces or more and that have been found associated with helvite and danalite are considered in this paper. A paper that contains a summary of all minerals recognized in the Iron Mountain deposits is in preparation.

Garnets

The associated garnets, andradite and grossularite, have already been mentioned. The variable index of refraction of the grossularite from the North End area is too high for normal grossularite and too low for normal spessartite or andradite. Although qualitative analysis shows that it contains manganese and iron, the iron-rich environment might well favor the predominance of the andradite molecule. Three different samples of isolated well-formed crystals of the grossularite, according to spectrographic examination by L. W. Strock, showed 0.08%, 0.13%, and 0.19% BeO. These samples were taken from the helvite-grossularite zone, but not from immediate association with helvite-bearing veinlets. These results suggest that the grossularite in the North End area is beryllium-bearing. Further investigation of this garnet is in progress at present.

Idocrase (*vesuvianite*)

Fibrous, beryllium-bearing idocrase is widely but sparingly distributed throughout the ribbon rock tactite, and occurs in larger concentrations in a heavily mineralized garnetiferous tactite high on the west slope of the North Peak (Fig. 1). It occurs also in fluorite-rich tactite in the lower part of Discovery Gulch.

The idocrase forms small, colorless to pale green or very pale yellow radiating aggregates of slender prismatic crystals in clusters ranging from 3 to 10 mm. in length.

Table 2 shows the optical properties of specimens from two widely separated localities (Fig. 1).

TABLE 2. OPTICAL PROPERTIES OF BERYLLIUM-BEARING IDOCRASE FROM IRON MOUNTAIN, NEW MEXICO

Locality	North Peak (West Side)		Pit near North End Peak	
	1	2	1	2
	Tetrag.	Tetrag.	Tetrag.	Tetrag.
ϵ	1.711	1.712	1.703	1.705
ω	1.718	1.722	1.709	1.710
B	.007	.010	.006	.005
Sign	—	—	—	—
2V (abnormal)	0° to 7°	5° to 6°		

The optical data agree with those for beryllium-bearing idocrase from Franklin, New Jersey (24) ($\epsilon=1.700$, $\omega=1.712$), the redetermined beryllium content of which has not as yet been published.

TABLE 3. CHEMICAL ANALYSIS OF BERYLLIUM-BEARING IDOCRASE FROM IRON MOUNTAIN, SIERRA AND SOCORRO COUNTIES, NEW MEXICO

Rollin E. Stevens, analyst

SiO ₂	36.19
Al ₂ O ₃	13.36
Fe ₂ O ₃	4.15
FeO	2.15
BeO	1.09*
MgO	2.42
CaO	32.02
Na ₂ O	.22
K ₂ O	.05
H ₂ O—	.43
H ₂ O+	.60
TiO ₂	Trace
F	3.22
MnO	4.48
ZnO	.43
B ₂ O ₃	.11
	100.92
—O=F	1.36
	99.56

* Average of two determinations, 1.07% and 1.10%.

Specific gravity slightly greater than 3.3. $\epsilon=1.711$, $\omega=1.718$.

A chemical analysis was made on carefully selected and purified material from North Peak. First the magnetite was removed from the crushed sample by use of an alnico hand magnet; then the minerals lighter than idocrase were floated off by heavy solutions; the concentrate, consisting of idocrase, garnet, and a few grains of fluorite, was separated by use of the Frantz isodynamic electro-magnet; and the final concentrate was then hand-picked. The results of the analysis are given in Table 3:

Spectrographic examination shows the Be, B, and Zn lines to be slightly stronger for the idocrase from near the North Peak, than for that near the North End Peak (Fig. 1). X-ray diffraction patterns are identical, and, though these patterns do not agree entirely with patterns of known specimens of idocrase, it is believed that the difference may be due to minute inclusions of extraneous material, or to slight alteration of the mineral itself.

The minerals associated with the North Peak idocrase, which in places forms about 2 to 3% of the rock mass, are magnetite, approximately 60%; fluorite, 34%; chlorite, garnet, iron oxides, etc., 3%; and tilleyite and rhodochrosite, 1%. The material examined represents selected specimens. Random samples from the same area would show a higher percentage of magnetite and a lower percentage of fluorite; garnet would equal or exceed the amount of fluorite.

Selected hand specimens from the North End Peak locality contain magnetite and fluorite in almost equal proportions. Chlorite is more abundant than it is in the North Peak deposit, and garnet is less abundant. No other minerals have been observed with the idocrase. At the North End Peak locality the material is apparently fresher and more coarsely crystallized.

Pink Epidotes

Pink to red members of the epidote group, ranging from pink zoisite (thulite) to piedmontite, are widely distributed throughout the iron-poor silicate rocks of Iron Mountain (Fig. 1). Thin blades of yellowish-green epidote and pale brown to colorless zoisite are commonly associated with the pink minerals. These pink minerals occur as incrustations on fracture faces in a fine-grained greenish-gray quartz-pyroxene-clinozoisite granulite, forming typical radiating sheaf-like aggregates. Some of the crystals of the piedmontite variety show a regular succession of growth ridges along their length that correspond in position and in outline to traces of repeated terminations. In some crystals the characteristic deep rhodinite-pink color fades to pinkish-brown toward the end farthest from the center of the cluster.



FIG. 4. Radial growth of pink zoisite (thulite) and clinozoisite with zeolites on surface of fine-grained clinozoisite-diopside granulite. Many of the needles of pale green clinozoisite change toward their outer ends into thulite ($\times 3$).

The optical data (Table 4) show a gradation from pink zoisite through pink clinozoisite to piedmontite. The variation in optical data shown in the study made by Schaller and Glass (27) based on samples that represent 14 localities from 12 states shows a continuous gradation from low-index pink zoisite to pink clinozoisite.

Table 4 shows the optical properties of two examples each of the low-index pink zoisite, the intermediate clinozoisite, and the highest-index piedmontite. Additional laboratory data show a continuous progression in optical variation from the lowest to the highest readings shown in the table below. The map (Fig. 1) indicates the distribution of some of the pink epidotes in the Iron Mountain area.

Most of the pink zoisite (thulite) occurs on the ridge south of Discovery Gulch (Fig. 1), where it is found encrusted on greenish-gray, iron-poor granulite and is associated with pink clinozoisite and colorless to brown zoisite. Pink clinozoisite is more widely distributed and occurs everywhere with the other varieties. Piedmontite is found most abundantly in the North Peak area. Although it is the richest in manganese and iron, this mineral falls in the lower end of the piedmontite range of indices of refraction.

TABLE 4. OPTICAL PROPERTIES OF PINK ZOISITE, CLINOZOISITE, AND PIEDMONTITE FROM IRON MOUNTAIN, NEW MEXICO

	Zoisite Ridge South of Discovery Gulch		Clinozoisite All localities		Piedmontite Canyon near North End Peak	
α	1.698	1.707	1.716	1.725	1.725	1.727
β	1.700	1.711	1.722	1.730	1.730	1.738
γ	1.705	1.718	1.726	1.740	1.750	1.755
B	0.007	0.011	0.010	0.015	0.030	0.028
Sign	+	+	+	+	+	+
2V	30°	55°	75°	80°	70°	75°
Disp.	Strong	$r < v$	mod.	variable	$r > v$	$r > v$
Pleoc.	X = Pink; Y = Cs.; Z = Yel.		X = Yel; Y = Cs.; Z = Pink		X = Yel; Y = Pink; Z = Red (strong)	

Note: Cs. = colorless; Yel. = yellow.

A spectrographic examination of the pink epidotes showed a trace of beryllium.

Tilleyite

Patches of a white mineral that resemble drusy quartz but about as hard as calcite were found in cracks and cavities in a sample of greenish tactite from the west slope of North Peak. The sample was collected because it contained an unusually large amount of pale green idocrase. The harder part of the sample is composed of yellowish-green andradite and magnetite, with a small patch of glassy clear fluorite. The white mineral has the optical properties of tilleyite. It is biaxial with large positive axial angle, and shows weak dispersion, $r < v$. Indices of refraction: $\alpha = 1.616$, $\beta = 1.635$, $\gamma = 1.651$. The mineral effervesces in hydrochloric acid like calcite and forms a silica gel. Spectrographic examination showed a trace of beryllium. Because of the small amount of material, no further study was made.

Thuringite (Chlorite)

A pale green to dark green brittle chlorite with pearly luster is found closely associated with coarsely crystallized fluorite in pods in the ribbon rock and in places with the grossularite. Spectrographic examination of the chlorite showed distinct beryllium lines. Other observed data correspond to normal thuringite.

THE HELVITE GROUP

The helvite group consists of three isomorphous species whose chemical composition is expressed by the general formula, $R_4Be_3Si_3O_{12}S$, with

R = Mn in helvite, Fe in danalite, and Zn in genthelvite; that is, the end members of the group are

Helvite	$\text{Mn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$
Danalite	$\text{Fe}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$
Genthelvite	$\text{Zn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$

The last name, genthelvite, is here given to the essentially zinc member of the helvite group, found in Colorado many years ago and described by Genth (8) in 1892. It is fitting that this mineral species bear the name of Genth. The name genthite has already been used to refer to a nickel-bearing deweylite. Therefore, we take pleasure in naming the zinc member of the helvite group *genthelvite*, and in this way honoring the memory of Frederick A. Genth, who first described the species.

The helvite group is generally recognized as a three-component system, although later writers seem to have overlooked the published (1892) analysis of a "danalite" that contained a high percentage of zinc. The zinc component has been mentioned by Goldschmidt (9), Bowley (2), and others, but particularly by Pauling (25) who explains the higher specific gravity (3.427) of the danalite from Rockport, Mass., over that of helvite (3.23 calculated) as due to the presence of about 40 per cent of the zinc end member. The only known occurrence of genthelvite is West Cheyenne Cañon, near St. Peter's Dome, El Paso County, Colorado, and the only known existing specimen is in the Genth Collection at Pennsylvania State College, State College, Pennsylvania. A brief summary of the essential properties of this mineral, taken in part from Genth's description, is as follows:

Genthelvite, $\text{Zn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$. Isometric, tetrahedral.

Forms: $d\{110\}$, $o\{111\}$, $o'\{1\bar{1}1\}$. No cleavage observed.

Pale rose-red to brownish owing to slight oxidation.

Isotropic, $n = 1.744$. $G = 3.66$. Transparent and nearly colorless in thin fragments.

Decomposed by acid, and in general resembles danalite.

None of the three minerals of the helvite group is known to occur in nature in the pure state; all contain both manganese and iron, and half of them also contain zinc. The helvite (analyses 1 and 2, Table 5) from Amelia, Virginia, contains the greatest quantity (96 per cent) of the manganese component; the danalite from Cornwall, the greatest quantity (70 per cent) of the iron component; and the genthelvite from Colorado the greatest quantity (85 per cent) of the zinc component. As the name helvite refers to members of the helvite group that consist dominantly of the manganese component $\text{Mn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$, the name danalite should be restricted to those members of the helvite group which consist dominantly of the iron component, $\text{Fe}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$, and genthelvite should refer

to members which consist dominantly of the zinc component, $\text{Zn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$.

Cooke's (5) analyses of danalite from Rockport and Gloucester, Mass., yield only 55 per cent of the iron component together with 32 per cent and 34 per cent, respectively, of the zinc component. It is interesting to recall Cooke's reason for giving the then (1866) new name danalite to this mineral. He says: "In its peculiar constitution the new mineral is allied to Helvin, although the two species have no outward resemblance. The holohedral character of its crystallization, the very large amount of iron and zinc entering into its composition, its color, luster, hardness, and other physical as well as chemical properties, all distinguish it from helvin and prove the mineral to be a new species." Most of these criteria would hardly suffice to establish a new species today.

Members of the helvite group may show considerable variation in properties and composition, due to the isomorphism of manganese, iron, and zinc, as is demonstrated by the helvite and danalite from the Lower Star body and the North End Peak areas of Iron Mountain, New Mexico, where the index ranges from 1.737 to 1.759. Similarly a range of from 1.742 (yellow material) to 1.754 (raspberry-red material) was found for the mineral from Bartlett, New Hampshire. One fragment from the Bartlett locality showed a rim of red enclosing the yellow variety.

The large, rude, reddish crystals of danalite from Cornwall contain in their crevices and cavities minute tetrahedra of both reddish-brown and yellow color, as described by Miers and Prior (23). These minute crystals "are mostly of the same colour [columbine-red to brick-red] as the main mass of the material, but some are yellowish, and one was found, which, while red at one end, was clear grayish-yellow at the other." The index of refraction of the red danalite (sample obtained from the British Museum) ranges from 1.756 to 1.759 with most of the grains 1.758. The palest colored danalite (pale pink) has an index of 1.753. The red danalite is clearer and more transparent than the paler colored variety and evidently represents the variety analyzed by Miers and Prior who state that in the preparation of the sample for analysis, "the most transparent pieces were picked out under the lenses."

Some members of the helvite group, however, are homogeneous for some localities. The helvite from Discovery Gulch shows consistently the same index of refraction (1.746) in all parts of the deposit, as does the danalite at Rockport (1.755). The helvite from Saxony shows only slight variation (1.728-1.733).

All available analyses of the members of the helvite group are given in Table 5, and are arranged in order of decreasing percentages of the manganese component, $\text{Mn}_4\text{Be}_3\text{Si}_3\text{O}_{12}\text{S}$.

TABLE 5. ANALYSES OF MINERALS OF THE HELVITE GROUP

	SiO ₂	BeO	MnO	FeO	ZnO	MgO	S	X*		Less O=S	
HELVITE:											
1. Amelia, Va.	25.48	12.63	50.24 ^a	2.03 ^b	—	—	4.96	5.10	100.44	2.48	97.96
2. Amelia, Va.	31.42	10.97	51.64 ^c	2.99	—	—	4.90	.36	102.28	2.45	99.83
3. Norway	33.13	11.46	49.10 ^d	4.00	—	—	5.71	—	103.40	2.85	100.55
4. Schwarzenberg	33.33	14.92	44.43	4.45	—	—	5.03	.77	102.93	2.51	100.42
5. Schwarzenberg	33.26	12.03	41.76 ^e	8.00	—	—	5.05	1.15	101.25	2.52	98.73
6. Lupikko	30.34	10.46	37.88	10.37	—	0.68	5.95	4.92	100.60	2.97	97.63
7. Sigtesö	32.85	11.19	39.68	13.02	—	—	5.71	1.40	103.85	2.85	101.00
8. Ilmen Mts.	32.49	13.52	35.41	15.12	—	—	5.77	.77	103.08	2.88	100.20
9. Argentina	32.65	12.20	30.79	14.75	4.89	2.24	6.01	—	103.53	3.00	100.53
10. Hörtokollen (Christiana Dist.)	31.95	13.17	28.46	15.55	7.65	—	5.86	—	102.64	2.93	99.71
11. Australia	31.82	13.90	28.00	15.80	7.76	—	5.75	—	103.03	2.87	100.16
12. Iron Mt., N. Mex.	31.54	13.60	26.51	18.02	5.61	—	5.34	2.06	102.68	2.67	100.01
DANALITE:											
13. Redruth, Cornwall	29.48	14.17	11.53	37.53	4.87	—	5.04	—	102.62	2.52	100.10
14. Rockport, Mass.	31.73	13.83	6.28	27.40	17.52	—	5.48	—	102.24	2.74	99.50
15. Gloucester, Mass.	29.88	14.72 ^f	5.71	28.13	18.15	—	4.82	.83	102.24	2.41	99.83
GENTHELVITE:											
16a. W. Cheyenne Cañon, Colorado	30.26	12.70	1.22	6.81	46.20	—	5.49	.51	103.19	2.74	100.45
16b. W. Cheyenne Cañon, Colorado ^g	—	—	1.5	6.1	46.0	—	—	—	—	—	—

* CaO, Al₂O₃, Na₂O, K₂O, TiO₂, H₂O.

HELVITE

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2. B. E. Sloan, *Chem. News.*, **46**, 195 (1882).
3. C. F. Rammelsberg, *Annalen d. Physik u. Chemie* (Pogg.), **93**, 453 (1854).
4. Miers and Prior, *Mineral. Mag.*, **10**, 10 (1892). (Recalculated after deducting 4.6% fluorite.)
5. J. F. Gmelin, *Annalen d. Physik u. Chemie* (Pogg.), **3**, 53 (1825), corrected by C. F. Rammelsberg, *Handb. d. Mineralchemie*, 701 (1860).
- 6, 8. Teich, *Mineral. Russlands*, **7**, 322, 323 (1866).
7. Bäckström, *Zeits. Krist.*, **16**, 176 (1890).
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10. V. M. Goldschmidt (*Videnskap. Skrifter*, No. 1, 396, 1911). *Zeits. Krist.*, **55**, 95 (1915).
11. H. Bowley, *Jour. Roy. Soc. W. Australia*, **18**, 83 (1932).
12. R. E. Stevens, *Am. Mineral.*, this issue.

DANALITE

13. Miers and Prior, *Mineral. Mag.*, **10**, 10 (1892).
- *14, 15. J. P. Cooke, *Am. Jour. Sci.*, Ser. 2, **42**, 73-79 (1866),

GENTHELVITE

- 16a. F. A. Genth, *Am. Jour. Sci.*, Ser. 3, **44**, 385, 1892.
- 16b. R. E. Stevens, *Am. Mineral.*, this issue.

^a Includes 8.66% Mn calculated as MnO.

^b Fe₂O₃, 2.26% calculated as FeO.

^c Includes 8.59% Mn calculated as MnO.

^d Includes 9.77% Mn calculated as MnO.

^e Includes 8.67% Mn calculated as MnO.

^f With Al₂O₃.

^g Partial analysis made on a minute quantity of material.

* Cooke's analysis on Rockport material was checked by Stevens.

On the basis of interpretation that the members of the helvite group may be considered as a three component system, the percentages of these three components, or end members, with the determined specific gravity (G) and index of refraction (*n*) of the minerals are shown in Table 7 below. The placement of these 16 members of the helvite group on a compositional basis is shown in Fig. 5. In this figure, the 2 per cent of the magnesium component in No. 6 and the 6 per cent of the magnesium component in No. 9, are added to the percentages of the manganese component.

TABLE 7. PERCENTAGES OF COMPONENTS CALCULATED FROM ANALYSES OF MEMBERS OF THE HELVITE GROUP, WITH DETERMINED SPECIFIC GRAVITY (G) AND INDEX OF REFRACTION (n)

No	Locality	Mn Comp.	Fe Comp.	Zn Comp.	G ^a	n	Mineral
1	Amelia	96	4	0	—	—	Helvite
2	Amelia	95	5	0	3.25	—	
3	Norway	92	8	0	3.17	—	
4	Schwarzenberg	91	9	0	3.20	—	
5	Schwarzenberg	84	16	0	3.17	—	
6	Lupikko ^c	79	21	0	3.30 ^b	—	
7	Sigtesö	75	25	0	—	—	
8	Ilmen Mts.	70	30	0	3.33	—	
9	Argentina ^d	64	28	8	3.29	1.74 ^e	
10	Hörtekollen	56	30	14	3.32	1.747	
11	Australia	55	31	14	3.31	1.765 ^f	
12	Iron Mountain	53	36	11	3.33	1.746 ^g	
13	Cornwall	22	70	8	3.35	1.758 ^g	Danalite
14	Rockport ^h	13	55	32	3.43	1.755 ^g	
15	Gloucester	11	55	34	—	—	
16	Colorado	2	13	85	3.66	1.744 ^g	Genthelvite

^a Rounded off to two decimals.^b Average of range 3.23–3.37.^c Includes two per cent of the magnesium component.^d Includes six per cent of the magnesium component.^e Given as slightly under 1.74.^f Probably too high. See text.^g By J. J. Glass.^h Given as 1.754 in Dana-Ford *Textbook of Mineralogy*.

TABLE 8. THEORETICAL COMPOSITIONS OF THE THREE COMPONENTS OF THE HELVITE GROUP

	Mn Component	Fe Component	Zn Component
MnO	51.12	—	—
FeO	—	51.44	—
ZnO	—	—	54.54
BeO	13.52	13.43	12.58
SiO ₂	32.46	32.25	30.19
S	5.78	5.74	5.37
	102.88	102.86	102.68
Less O=S	2.88	2.86	2.68
	100.00	100.00	100.00

The calculated percentages of the components given in Table 7 are based on the theoretical compositions of the three end-member components, as given in Table 8.

The determined specific gravities, as listed in Table 7, range from 3.17 to 3.66. From a study of these figures, the specific gravities are probably

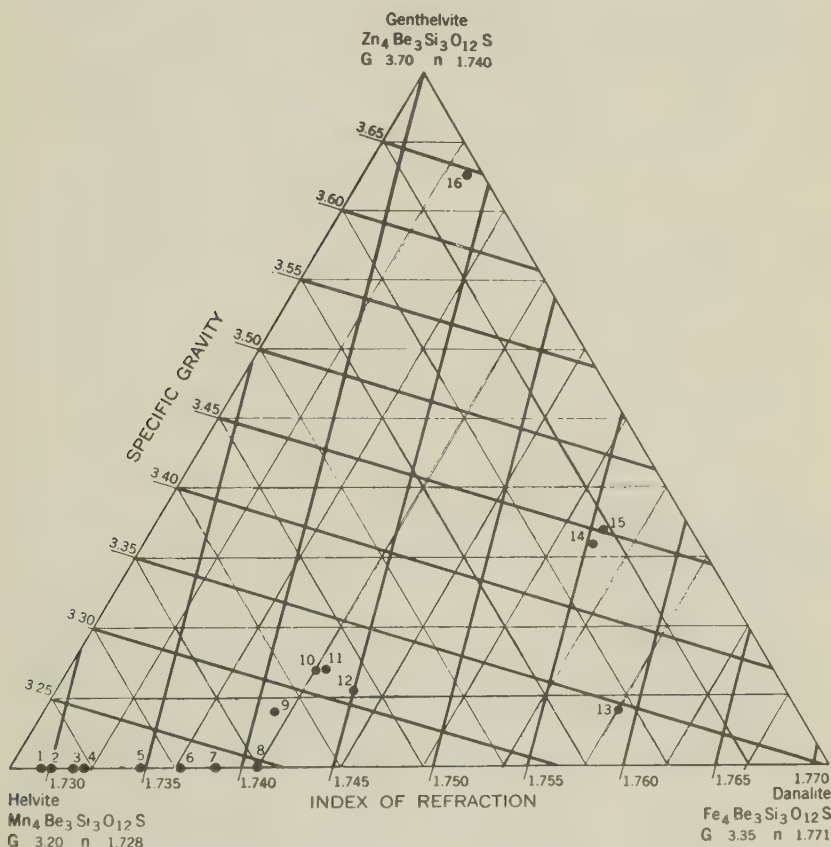


FIG. 5. Diagram showing the correlation of the variations in specific gravities and indices of refraction with the chemical composition of members of the helvite group.

close to 3.20, 3.35, and 3.70 for the manganese, iron, and zinc components respectively.

The specific gravity variation lines (heavy, solid) shown in Fig. 5 are based on these values. The following comparison of calculated and determined values confirms the approximate correctness of these figures.

The agreement between the calculated and determined specific gravities is close and indicates that the values given for the end member components are very nearly correct.

TABLE 9. COMPARISON OF CALCULATED AND DETERMINED SPECIFIC GRAVITIES (G) FOR THE HELVITE GROUP

Number	G Calculated	G Determined	Difference
1.	3.21	—	—
2.	3.21	3.25	— .04
3.	3.21	3.17	+ .04
4.	3.21 ^a	3.20	+ .01
5.	3.22 ^a	3.17	+ .05
6.	3.23	3.30 ^b	— .07
7.	3.24	—	—
8.	3.25	3.33	— .08
9.	3.29	3.29	0
10.	3.32	3.32	0
11.	3.32	3.31	+ .01
12.	3.31	3.33	— .02
13.	3.35	3.35	0
14.	3.44	3.43	+ .01
15.	3.45	—	—
16.	3.65	3.66 ^c	— .01

^a Pauling (25) calculated 3.23 from *x*-ray data.

^b Given as 3.23–3.37.

^c G = 2.626–2.661 given in *Dana*, Sixth Edition, Supplement, p. 1032, is a typographical error for 3.626 to 3.661.

Barth (1) calculated 3.24, 3.34, and 3.57 for the three components. The last value obviously is too low as Genth found 3.66 for the genthelvite (85 per cent Zn component) from Colorado.

In an attempt to correlate the indices of refraction with other recorded data for the helvite group, indices of refraction have been determined on as many samples as could be obtained for this purpose. Data in the literature are very incomplete. Determinations of indices of refraction have been made for only a few of the analyzed members of the helvite group. Of seven determinations in the literature only three are for analyzed material; one of these (No. 9) is approximate, one (No. 11) is obviously in error, and one (No. F in Table 10) is probably a misprint. Four new determinations on analyzed material, including the helvite from Discovery Gulch, Iron Mountain, New Mexico, have been made. Unfortunately, material from New Mexico with the highest and lowest indices is not available in quantity sufficient for chemical analysis. Nine additional determinations of indices were also made on unanalyzed sam-

ples (Table 10). Published indices have been included in the tabulation.

The index (1.765) given by Bowley (2) for helvite from West Australia (No. 11) is believed to be too high. He used measured proportions of iodides and piperine which when heated may or may not have formed a melt of the calculated index of refraction. That his melt probably did not have this high index is suggested by his statement that he obtained the same high value for the danalite from Rockport, whereas we found the lower value of 1.755. The helvite from West Australia has a calculated index of 1.743. Confirmation of the suggestion that Bowley's index value is too high lies in the very close equality of component composition of his helvite (No. 11) with Nos. 10 and 12 whose measured indices are 1.747 and 1.746, respectively. The specific gravities of Nos. 10, 11, and 12 are likewise almost identical.

The index of refraction, $1.737 \pm .003$ (Table 10 "F") given for danalite from Rockport, Mass., by Larsen (19) (1st edition) is probably a misprint for $1.757 \pm .003$, as we obtained 1.755 for the identical material (U.S.N.M. 45943) on which Larsen made his determination.

TABLE 10. INDICES OF REFRACTION ON UNANALYZED MEMBERS OF THE HELVITE GROUP
(Indices for members marked with a star (*) were determined for this paper)

	Locality	Index of Refraction	Remarks	
HELVITE:				
*A.	Schwarzenberg, Saxony	1.728-1.730	Variable	Specimens loaned by the U. S. National Museum, No. R-3395; and by Columbia University.
*B.	Silverton, Colorado	1.728-1.734	Variable	Sample contributed by Ward C. Smith.
*C.	Breitenbrunn, Saxony	1.733	—	Sample loaned by Columbia University.
D.	Butte District, Montana	1.734	Doubtful trace of zinc	D. F. Hewett (15).
*E.	Iron Mountain, New Mexico	1.737	—	Lower Star body.
F.	Rockport, Massachusetts	1.737	Probably a misprint for 1.757.	E. S. Larsen (19).
G.	Langesundfiord, Norway	1.739	—	Levy and Lacroix (21).
H.	Eureka Gulch, Colorado	1.74	No zinc	W. S. Burbank (4).
*I.	Bartlett, New Hampshire	1.742	Yellow variety	Sample contributed by Prof. Charles Palache, Harvard University, and similar material contributed by Lester W. Strock.
*J.	Amelia, Virginia	1.743	—	U. S. National Museum, No. R-3397.
DANALITE:				
*K.	Bartlett, New Hampshire	1.754	Red variety	See "I".
*L.	Rockport, Massachusetts	1.755	—	U. S. National Museum, No. C-2684.
*M.	Iron Mountain, New Mexico	1.750-1.759	Variable, no zinc	Collected at North End Peak.

A large number of calculations based on the indices of refraction recorded in Table 7 and Table 10 indicate that the indices for the end member components are probably close to the values: $n=1.728$ for the Mn-component, 1.771 for the Fe-component, and 1.740 for the Zn-component.

From these established values for the end member components, a comparison of the calculated and the determined indices for members of the helvite group, omitting the probably too high value given for the helvite from Australia (No. 11), is shown in the table below.

TABLE 11. COMPARISON OF CALCULATED AND DETERMINED INDICES OF REFRACTION (n) FOR THE ANALYZED MEMBERS OF THE HELVITE GROUP

Number	Locality	n Calculated	n Determined	Difference
4	Schwarzenberg	1.732	1.730 ^a	+ .002
9	Argentina	1.739	1.74	—
10	Hörtekollen (Christiana District)	1.743	1.747	— .004
12	New Mexico	1.745	1.746	— .001
13	Cornwall	1.759	1.758	+ .001
14	Rockport	1.755	1.755	.000
16	Colorado	1.744	1.744	.000

^a Not on analyzed material. Average value for four samples ranging from 1.728 to 1.733.

Two samples of analyzed helvites have the same index (1.728) as the Mn-component. These low values may be due to the presence of a small amount of magnesium which would lower the index of refraction appreciably. Only two of the sixteen analyses listed in Table 5 report any MgO, one (No. 9) showing 2.24 per cent MgO.

TABLE 12. CHARACTERISTICS, OCCURRENCES, AND ASSOCIATIONS OF ANALYZED MEMBERS OF THE HELVITE GROUP

	Locality	Color	Spec. Characteristics	Occurrence	Associated Minerals
HELVITE: 1, 2.	Amelia, Virginia	Sulphur yellow	Translucent, waxy, crystalline masses	Mica and feldspar pegmatite	Spessartite, amazonstone, microlite, monazite, etc.
3.	Norway (southern)	Sulphur yellow	Translucent crystals	Zircon syenite	Zircon, feldspars, etc.
4, 5.	Schwarzenberg, Saxony	Sulphur yellow	Translucent, waxy, tetrahedral crystals	In gneiss	Garnet, scheelite, quartz, fluorite, calcite.
6.	Lupikko, Finland	Reddish-brown	Translucent crystals 1½ inches through	Data not available	Magnetite and fluorite.
7.	Sigtö (Island)	Sulphur yellow to brown	Translucent to transparent crystals	Augite-syenite	Aegirite, nephelite, feldspar, etc.
8.	Ilmen Mountains, near Minsk	Yellow	Vitreous, translucent, large spherical masses	In pegmatite	Topaz, phenakite, monazite, pyrochlore, etc.
9.	Sierra de Cordoba, Argentina	Dark brown (stained)	Tetrahedral crystals, greasy luster	Contact metamorphic zone	Garnet, epidote, calcite, fluorite, chlorite, etc.
10.	Hörtekollen, Christiana District, Norway	Yellow to reddish	Tetrahedral crystals, vitreous	Contact metamorphic zone	Magnetite, fluorite, feldspar, etc.
11.	Mt. Francisco, West Australia	Carob brown	Oxidized angular masses up to 2 inches across	Not given	None given.
12.	Iron Mountain, Discovery Gulch, New Mexico	Amber to mahogany	Tetrahedral crystals, vitreous to resinous	Contact metamorphic zone, magnetite-tactite	Magnetite, fluorite, chlorite, etc.
DANALITE: 13.	Redruth, Cornwall	Columbine red	Large, rough tetrahedral crystals, vitreous	Not given. Specimen purchased	Quartz, arsenopyrite, chlorite.
14.	Rockport, Massachusetts	Flesh-red to gray	Crystal masses, octahedral, and grains, vitreous to dull	In granite	Lepidolite, fluorite, amazonstone, etc.
15.	Gloucester, Massachusetts	Rhodinite red	Translucent, vitreous	In granite	(Same).
GENTHELVITE: 16.	West Cheyenne Cañon, Colorado	Rose-red to brown	Crystal 15×17 mm. vitreous	Not given	Quartz and astrophyllite.

TABLE 13. CHARACTERISTICS, OCCURRENCES, AND ASSOCIATIONS OF UNANALYZED MEMBERS OF THE HELVITE GROUP^a

HELVITE:	Locality	Color	Spec. Characteristics	Occurrence	Associated Minerals
A.	Schwarzenberg, Saxony	Sulphur yellow	Translucent, waxy.	In gneiss	Garnet, scheelite, quartz, fluorite.
B.	Silverton, Colorado	Yellow to greenish yellow	Waxy, translucent, zoned	In veins of manganese silicates and carbonates	Rhodonite and rhodochrosite.
C.	Breitenbrunn, Saxony	Sulphur yellow	Vitreous, translucent	In veins of manganese silicates and carbonates	—
D.	Butte District, Montana	Lemon yellow	Waxy luster, grains	In ribbon rock tactite, contact metamorphic zone	Rhodonite, rhodochrosite, quartz, sulfides.
E.	Lower Star, Iron Mtn., New Mexico	Pale yellow	Vitreous luster	In granite	Fluorite, magnetite, chlorite.
F.	Rockport, Massachusetts	Flesh red	Vitreous crystalline mass	In pegmatite in augite-syenite	Lepidolite, fluorite, feldspar.
G.	Langesundfjord, Norway	Yellow	Translucent	In pegmatite in augite-syenite	Aegirite and nephelite.
H.	Eureka Gulch, Colorado	(Same as "B" above)	Translucent to transparent	In iron mines	Fluorite, magnetite, sphalerite, galena, etc.
I.	Bartlett, New Hampshire	Honey yellow	Translucent, waxy luster	In feldspar and mica pegmatite	Spessartite, monazite, microcline, amazonstone.
J.	Amelia, Virginia	Sulphur yellow	Translucent	In iron mines	Magnetite, fluorite, galena, sphalerite.
DANALITE:	Bartlett, New Hampshire	Flesh red	Translucent	In iron mines	Fluorite, grossularite, magnetite, chlorite, etc.
K.	Rockport, Mass.	Same as No. 14 (Table 12), and same as "F" above.	Translucent	Contact metamorphic zone, ribbon rock tactite	—
L.	North End Peak, Iron Mtn., New Mexico	Creamy to honey yellow	Translucent	—	—

^a Refer to Table 12.

Values of a_0 were measured by Joseph M. Axelrod of the Geological Survey for the several available members of the helvite group with the results shown in Table 14. The data of Barth (1) and Pauling (25) are included.

TABLE 14. MEASURED VALUES OF a_0 FOR MEMBERS OF THE HELVITE GROUP

Mineral	Locality	Composition			a_0
		Mn	Fe	Zn	
Helvite	Saxony ^a	90	10	0	$8.273 \pm .005$. Axelrod.
Helvite	Saxony	90	10	0	8.25. Pauling.
Helvite	Hörtekollen	56	30	14	8.19. Barth.
Helvite	New Mexico	53	36	11	$8.21 \pm .02$. Axelrod.
Danalite	Cornwall	22	70	8	$8.199 \pm .005$. Axelrod.
Danalite	Rockport	13	55	32	$8.155 \pm .005$. Axelrod.
Genthelvite	Colorado	2	13	85	$8.115 \pm .005$. Axelrod.

^a Composition given by Pauling.

The values of a_0 determined by Barth and Pauling fall within the range of the values measured by Axelrod, but Gottfreid's (10) value of 8.52 for a helvite of unstated origin must be considerably in error.

Based on the measurements made by Axelrod, as given above, the extrapolated values of a_0 for the end member components are 8.27, 8.18, and 8.10 for the Mn, Fe, and Zn members, respectively.

Calculated values of a_0 based on the values just given, agree closely with the measured values (Table 15).

TABLE 15. COMPARISON OF CALCULATED AND MEASURED VALUES OF a_0 .

Mineral	Locality	Calculated a_0	Measured a_0
Helvite	Saxony	8.261	8.273
Helvite	Saxony	8.261	8.25
Helvite	Hörtekollen	8.219	8.19
Helvite	New Mexico	8.219	8.21
Danalite	Cornwall	8.193	8.199
Danalite	Rockport	8.166	8.155
Genthelvite	Colorado	8.114	8.115

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It has been possible, through the kind cooperation of several of our colleagues, to supplement in part some of the lacking data for analyzed samples. Professor Charles Palache of Harvard University kindly furnished some of Cooke's type danalite from Rockport, Mass., as well as danalite from Bartlett, New Hampshire. Samples from these two localities likewise were sent by Dr. Lester W. Strock. Some fragments of danalite, high in iron, from Redruth, Cornwall, were generously furnished by Dr. W. Campbell Smith of the British Museum; Professor Paul F. Kerr of Columbia University kindly loaned samples of helvite from Saxony; samples of helvite and danalite were also loaned by Mr. E. P. Henderson from the United States National Museum; and Professor William M. Myers of Pennsylvania State College graciously contributed some fragments of the high zinc "danalite" (genthelvite) from West Cheyenne Cañon, Colorado, analyzed and described by Genth in 1892. Specimens from this locality labeled danalite received from Dr. Harry Hess of Princeton University and from Dr. George Switzer of Yale University, proved to be pink zircon. Dr. George T. Faust of the Geological Survey kindly assisted in locating the sample of genthelvite. Acquisition of these specimens of analyzed material enabled us to supplement materially the list of indices of refraction for the helvite group. The writers are greatly indebted to these gentlemen for their valuable assistance.

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HYDROTUNGSTITE, A NEW MINERAL FROM ORURO, BOLIVIA

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ABSTRACT

A survey of the literature on hydrous tungstic oxide reveals that only one form, tungstite (H_2WO_4) has been established as a naturally-occurring mineral. A second hydrous oxide has been encountered in a study of material from Calacalani, Department of Oruro, Bolivia. It has the composition $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$ and has been named *hydrotungstite* to show its relationship to tungstite. It occurs in minute green tabular crystals as an alteration product of ferberite. The physical and optical properties of hydrotungstite are described and chemical and x-ray data are given. Artificial $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$ has been prepared which corresponds to the natural mineral in structural and optical constants. Dehydration data indicate that the second molecule of water is held in a different manner from the first. It is believed, as a result, that the formula of tungstite may be best expressed as H_2WO_4 and that of hydrotungstite as $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$.

PREVIOUS WORK

The first mention of the occurrence of tungstic ocher in nature was made by Silliman (1822). He recorded the discovery of a "massive yellow oxid of tungsten" at Lane's Mine, near Huntington, Connecticut. This material was assumed to have the composition WO_3 and was so described in the literature for a number of years. Following Silliman's discovery, the mineral was noted by others in various tungsten deposits. By 1858, such names as wolframochre (Hausmann—1847), scheelsaure (Naumann—1852) and wolframine (Greg and Lettsom—1858) had been applied to what was apparently the same material. Dana (1868) first employed the name "tungstite" for anhydrous WO_3 and suggested that this name be used to replace the other less desirable terms. Up to this time, no record had been made of a water determination on the mineral.

Carnot (1874) described specimens of tungsten ocher from Meymac, France, and applied the name "meymacite" to the mineral. Carnot's samples were mixtures of limonite, scheelite and hydrous tungsten oxide. The analyses of meymacite varied in water content from 6.85% to 12.93%, and Carnot concluded that the material was a mixture of tungstite (anhydrous WO_3) and a hydrous tungstic oxide. He noted the impure character of the samples, as well as the wide variation in water content and after subtracting for the impurities, suggested that the formula of "meymacite" was probably " $2\text{WO}_3 \cdot 5\text{HO}$ or $\text{WO}_3 \cdot 2\text{HO}$."

After Carnot's description of "meymacite," the name was employed for some time for any water-bearing oxide of tungsten. Hoffman (1896), for example, described "meymacite" from Beauce County, Quebec, which contained 7.2% H_2O .

Lovisato (1907) reported chemical analyses of hydrous tungstic oxide from Sardinia, and considered the material a mixture of tungstite and "meymacite." He appears to have recognized that the supposedly anhydrous tungstite of Silliman was hydrous but failed to ascertain the ratio of WO_3 to H_2O in either tungstite or "meymacite" because of the impure nature of his samples.

Walker (1908) indicated the probable identity of Carnot's "meymacite" and Silliman's earlier tungstite. He obtained a relatively pure hydrous tungstic oxide from Salmo, British Columbia, which carried 7.20% H_2O . This water content corresponds to a theoretical ratio $\text{WO}_3:\text{H}_2\text{O}$ of 1:1. Walker believed that the Salmo material corresponded to the mineral listed by Dana as tungstite and suggested that this name be applied to the monohydrate, and that Carnot's name "meymacite" should be abandoned. Walker's conclusions appear to have been generally accepted. Hess (1917), for example, says "Tungstite (hydrous tungsten oxide, $\text{WO}_3 \cdot \text{H}_2\text{O}$), or tungsten ocher, was originally described as free from water, and was later named meymacite by Carnot, a French chemist, who thought he had discovered a new mineral because it contained water, but Walker has shown that water is a normal constituent of tungstite." Later optical determinations by Larsen (1921) were made on type material from Salmo.

Ahlfeld (1932) reviewed the tungsten deposits of Bolivia and in the course of his discussion of the Oruro district, mentioned the occurrence of two forms of tungstite which differed in their water content. Impure samples prevented the establishment of the chemical composition of each.

While some of this earlier work may have suggested that two water-bearing tungstic oxides occur in nature, the only one which has been satisfactorily separated, analyzed and described is the monohydrate, tungstite, established by Walker.

Three other hydrous tungsten minerals have been described and should be mentioned here. Schaller (1911) described ferritungstite from Germany, Washington. On the basis of his chemical analyses he assigned the formula $\text{WO}_3 \cdot \text{Fe}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$ to this mineral. Scrivenor and Shenton (1927) described thorotungstite from the Federated Malay States and considered it to be related to tungstite, but to contain appreciable quantities of ThO_2 , ZrO_2 and the rare earths. Schaller (1932), in studying cuprotungstite from Cave Creek, Arizona, found this mineral to be hydrous and assigned to it the formula $\text{WO}_3 \cdot 2\text{CuO} \cdot \text{H}_2\text{O}$. X-ray and optical studies of these three minerals show that they differ from the two simple hydrous tungstic oxides.

ACKNOWLEDGMENTS

About twenty-four years ago, through the efforts of the late Professor A. J. Moses, a suite of tungsten specimens from Calacalani, Department of Oruro, Bolivia, was added to the Columbia University collection. Notes and memoranda in the departmental files indicate that Professor Moses had examined the material with care and had recognized the presence of two hydrous tungstic oxides. Unfortunately the study had not been completed at the time of his death. Recently other specimens from Calacalani have been secured, new determinations made and more positive data accumulated. While it has not been possible to include all of Professor Moses' observations we wish to acknowledge the assistance of data which, even after a long lapse of time, have been most helpful.

The writers also wish to take this opportunity to thank Dr. H. E. Merwin of the Geophysical Laboratory who kindly supplied high index melts with low melting points which were used in the determination of the indices of tungstite; and Dr. Roland B. Snow of the U. S. Steel Corporation, Research Laboratories, for his helpful suggestions on the preparation and use of the sulfur-phosphorus-methylene iodide liquids employed in determining the indices of hydrotungstite. We also wish to acknowledge the assistance of the Penrose Fund of the Geological Society of America for funds used to obtain chemical analyses. Dr. A. L. Parsons of the University of Toronto and the Royal Ontario Museum has kindly assisted by providing tungstite from Salmo, B. C., representing the late Professor T. L. Walker's original material. Dr. E. A. Lucas, Vice-President of the Molybdenum Corporation of America, has generously cooperated by furnishing artificial H_2WO_4 together with an analysis.

TUNGSTITE

The occurrence of tungstite at Calacalani, Bolivia, has been referred to by Hess (1921) and Ahlfeld (1932). According to the latter the chief ore mineral is ferberite which occurs with pyrite and stibnite in a quartz-siderite gangue replacing schist. The tungstite is found in the oxidized zone of the deposit where it has formed as an alteration product along cleavages and fractures of the ferberite.

Physical Properties

Tungstite occurs as rounded aggregates which are light yellow, greenish-yellow or dark orange-yellow in color. These aggregates vary from one to three mm. in diameter and consist of radiating crystals which range in length from 5 to 75 microns and in width from 3 to 20 microns.

Earthy incrustations on ferberite and quartz are also common. Occasional isolated crystals may be seen, but these are too small for goniometric measurement.

The material is characterized by a resinous luster when fresh but becomes earthy upon further alteration. The hardness is between 1 and 2. The specific gravity was not determined with sufficient accuracy to justify recording, but is apparently somewhat greater than the value for hydrotungstite. The specific gravity given by Walker (1908) as corrected by subtracting the effect of impurities in the Salmo material is 5.517. Before the blowpipe the mineral gives the usual blue color of tungsten in the salt of phosphorus bead. Fused with sodium carbonate and dissolved in HCl the solution assumes a deep blue color upon the addition of zinc. Heated alone in forceps or on charcoal, tungstite slowly bleaches, then darkens and finally volatilizes without leaving a sublimate. In the closed tube it gives off abundant water. The mineral is virtually insoluble in acids but dissolves readily in warm NH_4OH .

Optical Properties

Under the microscope the small crystals appear to be simple orthorhombic prisms with angles of 82 and 98 degrees. They are terminated by the basal pinacoid {001}. Cleavage parallel to this direction is perfect and results in thin plates of rhombic outline.

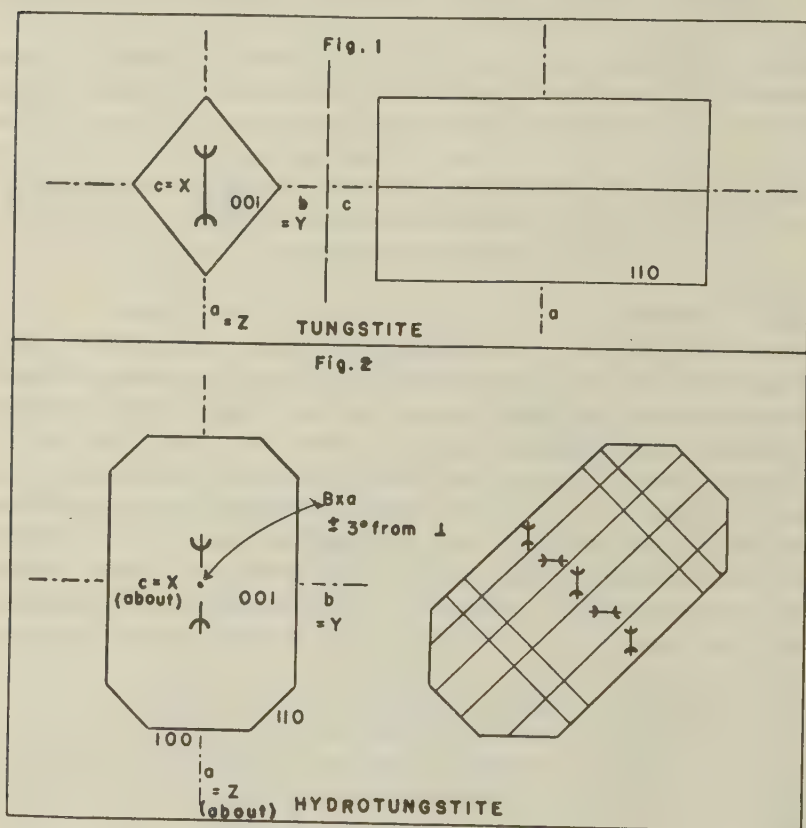
The indices of refraction as determined with sulfur-phosphorus-methylene iodide liquids are: $\alpha=1.82$, and $\gamma=2.04$, both ± 0.02 . These are somewhat lower than corresponding values listed by Larsen (1921) who gives $\alpha=2.09$, $\beta=2.24$ and $\gamma=2.26$ for the Salmo tungstite. In this connection it should be noted that the indices of refraction of this material change as the water is driven off. Since tungstite begins to lose water at 120° , attempts to determine the indices with melts which become liquid only above this temperature may give erratic results.

The birefringence, $n_\gamma - n_\alpha = .22$, but this is difficult to check in fragment mounts due to the high body color of the mineral. A strong change in relief observed as the stage is rotated above a single nicol is confirmatory.

The absorption in the longitudinal sections is marked, changing from colorless along X to deep yellow along Y or Z. In the rhombic section the mineral is not noticeably pleochroic, but with a dichroscope a difference in color may be observed with the Z-direction darker than the Y-direction. Thus the absorption may be expressed $Z > Y > X$. This differs from that given by Larsen (1921) who records the absorption of the Salmo tungstite as $X > Y > Z$.

The extinction is parallel to the length in longitudinal sections and parallel to the diagonals in rhombic sections.

The trace of the optic plane on cleavage fragments is parallel to the long diagonal of the rhombic outline. The angle $2V$ as measured on the universal stage is 27° and the acute bisectrix is X , thus the mineral is optically negative. The crystals are elongated parallel to X . Figure 1 shows the orientation of the crystals.



FIGS. 1 and 2. Orientation diagrams for tungstite and hydrotungstite.

Chemical Data

Chemical analyses of the Calacalani tungstite, artificial H_2WO_4 and the Salmo material are given in Table 1. The analyses of the natural minerals are expressed in terms of the mineral constituents in Table 2. Separate chemical analysis has shown that the ferberite from Calacalani

carries only one-half of one percent MnO and since the samples of the hydrous oxides which were submitted for analysis from this locality contained only small amounts of ferberite, the manganese content is disregarded in the calculations. In Table 3 the tungstite content of each analysis has been recast to 100% and is compared with the theoretical composition of pure H_2WO_4 .

HYDROTUNGSTITE

Physical Properties

A second alteration product of ferberite from Calacalani is a green mineral to which the name hydrotungstite is assigned.

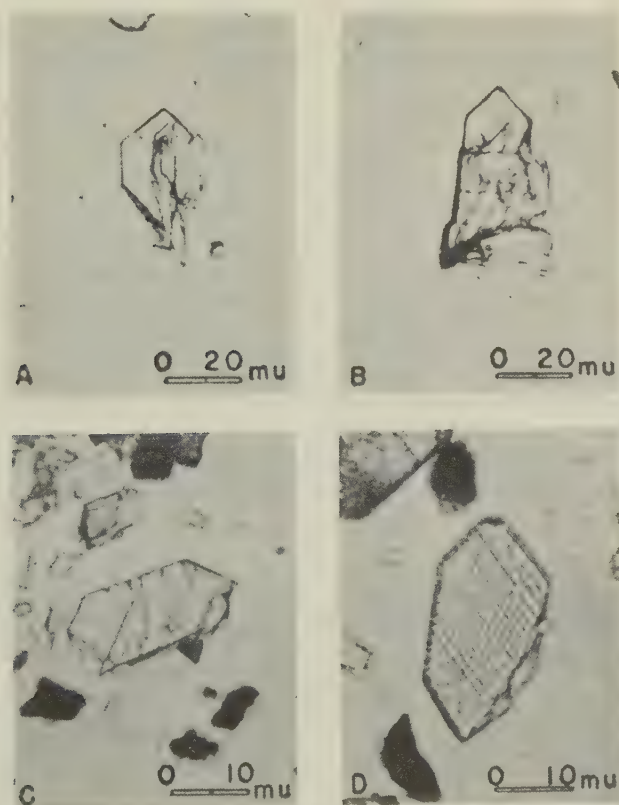


FIG. 3. Photomicrographs of hydrotungstite. Note twinning lamellae visible even under ordinary light. This is due to the great difference in relief of lamellae of opposite orientation. (A and B = $\times 500$; C and D = $\times 1000$. Reproduced without reduction of the photomicrographs.)

It occurs as platy crystals which vary in maximum dimension from 5 to 75 microns. These crystals are usually intergrown and twinned and even under high magnification, simple crystals are rarely seen (Fig. 3). No crystals suitable for goniometric measurement were found.

The color when freshly broken is dark green but may become yellowish upon continued exposure to the air. The luster is vitreous, becoming dull upon exposure. Hydrotungstite has a hardness of about 2.

TABLE 1. CHEMICAL ANALYSES

	Tungstite			Hydrotungstite	
	(1)	(2)	(3)	(4)	(5)
WO ₃	91.30	86.20	91.03	80.31	85.49
H ₂ O	7.46	7.72	8.75	12.52	14.39
SiO ₂	.96		.04	6.65	
Fe ₂ O ₃	.18	4.14	.05	.08	
FeO	n.d.	1.21		n.d.	
CaO	—	.54		—	
MoO ₃	n.d.		.07	n.d.	
NH ₃	n.d.			n.d.	.01
Chlorides	n.d.		.02	n.d.	
Total	99.90	99.81	99.96	99.56	99.89

(1) Tungstite, Calacalani, Bolivia. F. A. Gonyer, analyst.

(2) Tungstite, Salmo, B. C. T. L. Walker (1908)

(3) Artificial H₂WO₄. Sample and analysis kindly furnished by the Molybdenum Corp. of America.

(4) Hydrotungstite, Calacalani, Bolivia. F. A. Gonyer, analyst.

(5) Artificial H₂WO₄ · H₂O. A. M. Morely (1930).

The specific gravity as determined on a sample weighing about one-half gram utilizing the pycnometer is 4.60. The sample represented the residue from treatment with a high intensity magnet to remove ferberite and a bromoform separation to remove lighter gangue.

The blowpipe reactions are similar to those of tungstite. The added water is noticeable in the closed tube when compared directly with that of tungstite, but probably would not be distinguishable without direct comparison. In the forceps or on charcoal, the mineral decrepitates slightly, turns yellow, darkens and finally volatilizes. As with tungstite, the mineral is insoluble in ordinary acids but is readily dissolved by NH₄OH.

TABLE 2. ANALYSES IN TERMS OF THE MINERAL CONSTITUENTS.

	(1) Tungstite Calacalani, Bolivia	(2) Tungstite* Salmo, B.C.	(4) Hydrotungstite Calacalani, Bolivia
Tungstite	98.26	87.11	—
Hydrotungstite	—	—	92.61
Ferberite	.68	5.09	.30
Quartz	.96	—	6.65
Scheelite	—	2.78	—
Limonite	—	4.83	—
	99.90	99.81	99.56

* Recast with excess H₂O in tungstite for comparison with other analyses.

Optical Properties

Under the microscope, hydrotungstite is seen to occur as tiny green plate-like crystals which show polysynthetic twinning. The most prominent form is the basal pinacoid and fragment mounts are made up almost entirely of tiny crystals resting on a pinacoidal face. These basal plates are bounded by prisms {110} and the two pinacoids, {100} and {010}. In some of the mounts examined on the universal stage, low-angle domes were also seen but no measurements were possible.

The intersection of the vertical pinacoid faces makes an angle of 90 degrees. The optic plane was found to be parallel to the {010} plane. Figure 2 illustrates the orientation of hydrotungstite as determined from microscopic examination. Polysynthetic twinning is prominent parallel to the prism faces and forms a fine grid-like structure in many cases. In such instances the orientation of adjacent twin lamellae is reversed (Fig. 2).

The indices of refraction of hydrotungstite as determined according to the method of West (1936) with sulfur-phosphorus-methylene iodide liquids (Na-light) are: $\alpha = 1.70$, $\beta = 1.95$ and $\gamma = 2.04$, all ± 0.02 . The birefringence as calculated from the refractive indices is 0.34.

Imperfect cleavage parallel to {010} may be seen in some crystals. The extinction as measured against the basal plane on crystals tilted to have the plane appear as a line corresponding to the edge {001} \wedge {010} is three degrees. On this basis it seems likely that hydrotungstite is monoclinic.

Fragments mounted in balsam yield an absorption corresponding to that of tungstite; namely $Z > Y > X$, with Z = dark green, Y = yellow-

green (not markedly different from Z unless observed through a dichroscope), and X= colorless. Few fragments were noted which showed the X-direction since the platy character of the crystals caused this direction to lie perpendicular to the stage of the microscope.

TABLE 3. COMPOSITIONS OF TUNGSTITE AND HYDROTUNGSTITE.*

<i>Tungstite</i>				
	Theoretical	Calacalani, Bolivia Analysis (1)	Salmo, B. C.† Analysis (2)	Artificial H_2WO_4 Analysis (3)
WO_3	92.80	92.41	91.93	91.23
H_2O	7.20	7.59	8.07	8.77
Ratio	1:1	1:1.059	1:1.134	1:1.239
$WO_3:H_2O$				
<i>Hydrotungstite</i>				
	Theoretical	Calacalani, Bolivia Analysis (4)	Artificial $H_2WO_4 \cdot H_2O$ Analysis (5)	
WO_3	86.57	86.48	85.59	
H_2O	13.43	13.52	14.41	
Ratio				
$WO_3:H_2O$	1:2	1:2.015	1:2.170	

* All analyses recast to 100%.

† Recast with excess H_2O in tungstite for comparison with other analyses.

Chemical Data

Analyses of hydrotungstite from Calacalani and artificial $H_2WO_4 \cdot H_2O$ are shown in Table 1. The natural mineral is recomputed in terms of its mineral constituents in Table 2 and both analyses are recast to 100% in Table 3. The analyses agree quite well with the theoretical ratio $WO_3:H_2O$ of 1:2.

Artificial $H_2WO_4 \cdot H_2O$

Morely (1930) made a chemical and x-ray study of the various artificial tungstic acids. In the course of his work he produced artificial $H_2WO_4 \cdot H_2O$. Using Morely's method, the writers prepared a small quantity of the material for comparison with the natural mineral. Ten grams of ammonium tungstate $(NH_4)_6W_7O_{24} \cdot 6H_2O$, were dissolved in 225 cc. of distilled water. This solution was poured slowly into 250 cc. of

1.126 *N* HCl. The mixture was held at 20°C. and stirred constantly during this operation. A yellowish-white precipitate formed which was allowed to settle. This was carefully washed with distilled water. Decantation was continued for about 24 hours when the liquid suddenly assumed a silky sheen with a darker yellow color. The precipitate was then filtered and dried at 35°C.

Microscopic examination of the precipitate indicated that it was the same as that produced by Morely. Figure 4 illustrates the type of crystals produced. The crystals agree in their optical properties with those described under the natural mineral. Twinning was prominent but simple crystals were more common than in the natural material. An *x*-ray diffraction pattern of the artificial product is shown as Fig. 5F and corresponds to that of the Calacalani hydrotungstite.

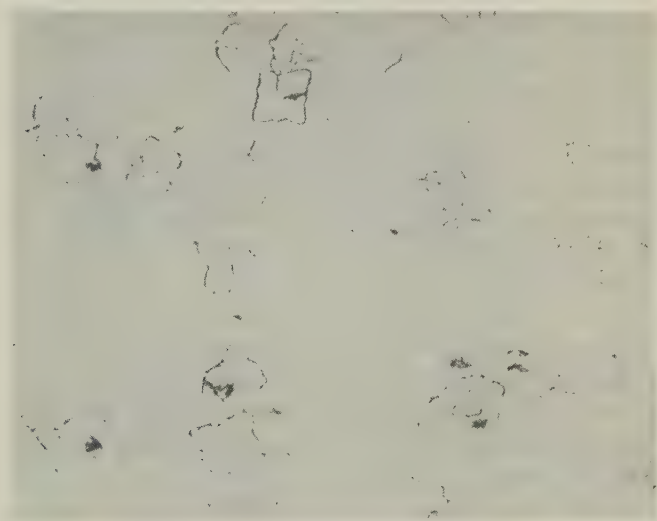


FIG. 4. Artificial $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$. ($\times 1000$) Note cruciform twins. (Reproduced without reduction of photomicrograph.)

Buchholz (1940) also studied artificial $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$ which he produced by adding HCl to a solution of silver tungstate. His description and illustrations indicate that he was dealing with the same compound.

X-RAY STUDIES

Samples of both tungstite and hydrotungstite have been selected with care for *x*-ray diffraction studies. Both have been checked for purity with the microscope and it is believed that the lines on the patterns secured may be attributed entirely to these minerals.

Although a few preliminary patterns were taken with molybdenum radiation, the data recorded are based entirely upon K-series reflections from an iron target. Crystals as yet found have been too small to yield results with any of the recognized single crystal methods. Powder cameras have been used entirely, both the Debye-Scherrer and the Phragmen-Bohlin types being employed. Samples have been kept in motion throughout exposure to avoid preferred orientation.

The technique of *x*-ray powder studies with the Phragmen-Bohlin camera has become well recognized in recent years as one of the more precise methods. The three camera system as employed covers the range of a single Debye-Scherrer photograph, allowing a determination of the interplanar spacings with greater certainty.

Comparative photographs of tungstite and hydrotungstite for the three different Phragmen-Bohlin cameras are shown in Fig. 6. Since the pictures compared in each case were taken in the same camera the dimensions of the exposed areas of the films for two cameras of corresponding position are substantially the same. With this in mind the pronounced difference between the patterns of tungstite and hydrotungstite in the inner, middle and outer cameras is convincing evidence of the difference in crystallization of the two minerals.

Computations of approximate $\sin^2 \theta$ values and corresponding interplanar spacings in Angstrom Units are shown in Table 4. Although in the patterns upon which the table is based alpha-1, alpha-2 and beta lines of the K-series of iron are represented, only the alpha-1 lines of the more intense reflections have been recorded. The intensities of the lines have been compared approximately and those with an intensity less than one on the arbitrary scale chosen have been omitted from final computation.

The Debye-Scherrer photographs have been used for more general comparison. Here again the patterns of tungstite and hydrotungstite yield numerous lines, the two differing widely in distribution. In addition to the comparison of tungstite and hydrotungstite the Debye-Scherrer patterns have been used for the comparison of tungstite from different sources. In this connection four tungstite patterns secured from different sources are shown in *A*, *B*, *C*, and *D* of Fig. 5. Here the pattern of tungstite from Calacalani, Bolivia, may be seen to agree with tungstite from Salmo, B. C., and also artificial H_2WO_4 . At the same time a sample of hydrotungstite from Calacalani from which one molecule of water has been removed by heating may be observed to yield the tungstite pattern.

The last two patterns of Fig. 5 (*E* and *F*) represent hydrotungstite. One is hydrotungstite from Calacalani, Bolivia. The other is artificial $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$.



FIG. 5. X-ray diffraction patterns of tungstite and hydrotungstite.

- A. Tungstite, Calacalani, Bolivia
- B. Tungstite, Salmo, B.C.
- C. Artificial H_2WO_4
- D. Hydrotungstite, Calacalani, Bolivia, converted to tungstite by heating.
- E. Hydrotungstite, Calacalani, Bolivia
- F. Artificial $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$.

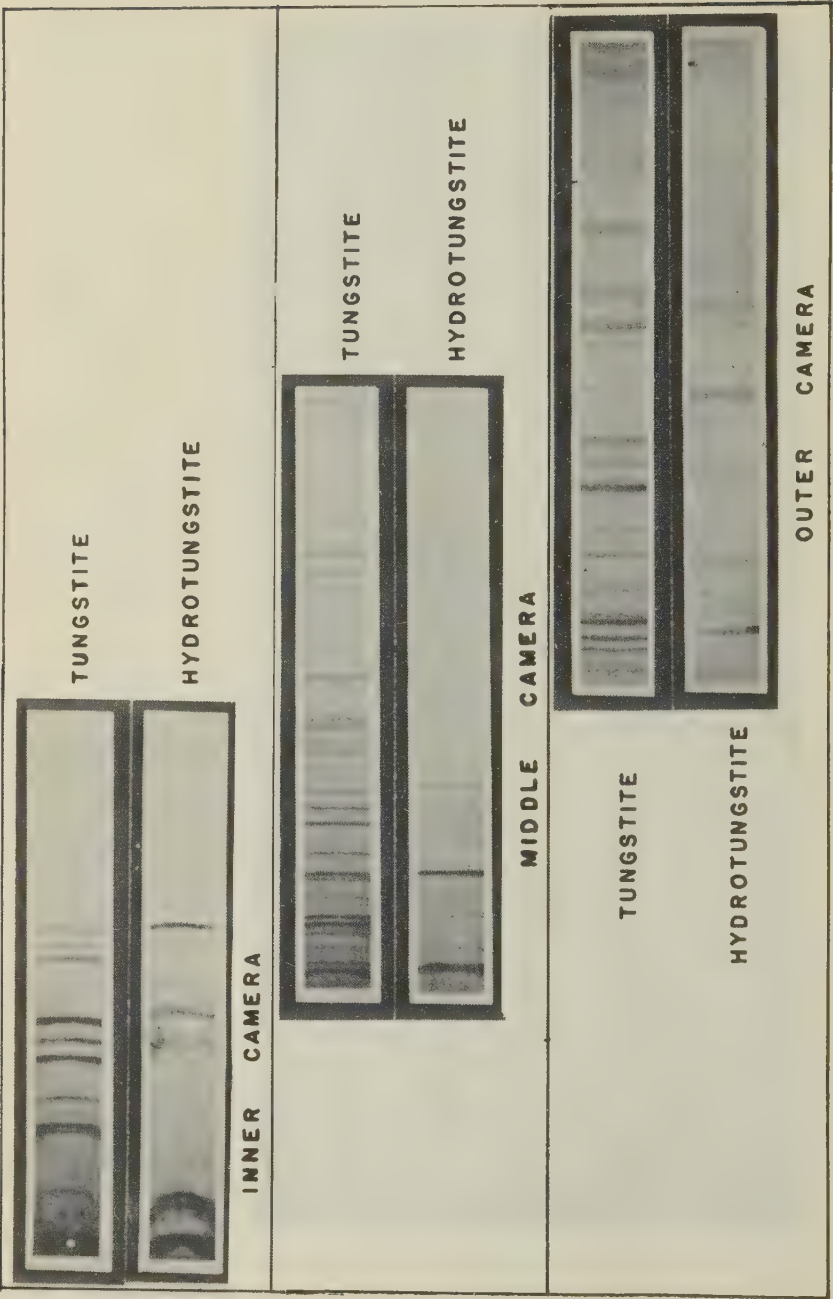


FIG. 6. Phragmen-Bohlin camera photographs of tungstite and hydrotungstite.

TABLE 4
X-RAY DIFFRACTION DATA FOR THE MORE INTENSE LINES OF
BOHLIN-PRAGMEN CAMERA PHOTOGRAPHS

Tungstite					Hydrotungstite				
Camera	Arc in mm.	Est. Intensity	$\sin^2 \theta$	d in AU.	Camera	Arc in mm.	Est. Intensity	$\sin^2 \theta$	d in AU.
Inner	2.8	10	.076796	3.49	Inner	3.6	10	.077814	3.46
	10.6	2	.089116	3.24		8.6	5	.085828	3.30
	20.9	3	.106962	2.95		10.45	5	.088886	3.24
	21.6	6	.108227	2.94		41.2	4	.146031	2.53
	26.65	4	.117590	2.82					
	33.2	9	.130181	2.68			1	.148093	2.51
	36.2	6	.136063	2.62					
	39.5	9	.142737	2.56		42.2	1	.148093	2.51
	49.55	4	.163953	2.39		55.45	8	.177056	2.30
	51.6	2	.168294	2.35					
	54.45	3	.174705	2.31					
	69.3	1	.208617	2.12		84.0	2	.244008	1.96*
	75.7	1	.223983	2.04*					
	81.5	2	.236046	1.99*					
	83.8	1	.243981	1.96*					
Middle	0.75	2	.220993	2.06*	Middle	4.35	5	.245354	1.95*
	3.10	5	.240009	1.97*		20.0	6	.315726	1.719
	4.30	3	.245150	1.95*					
	6.95	2	.256721	1.907					
	9.35	2	.267318	1.868					
	10.90	6	.274246	1.845					
	12.22	5	.280182	1.825					
	15.27	2	.294045	1.782					
	18.20	3	.307427	1.742					
	19.30	6	.312656	1.728					
	22.7	4	.328452	1.686					
	27.6	6	.350967	1.631		34.25	3	.383822	1.559
	30.1	5	.363978	1.601					
	32.72	3	.376696	1.574		48.20	1	.452770	1.436
	39.5	4	.409968	1.509					
	40.8	3	.416410	1.497					
	43.3	3	.428815	1.475		56.40	1	.493823	1.375
	51.6	3	.470301	1.409					
Outer	2.10	2	.522303	1.337	Outer	8.45	3	.559832	1.291
	3.30	1	.529385	1.328					
	5.75	4	.543980	1.310					
	7.40	5	.553744	1.298					
	10.20	6	.570153	1.2794					
	11.35	3	.576903	1.2778		20.10	1	.627657	1.2194
	15.35	2	.600434	1.2467					
	21.35	3	.635099	1.2122					
	25.70	2	.659811	1.1893					
	30.55	1	.686857	1.1656					
	31.90	6	.694278	1.1594		34.85	1	.709880	1.1465
	36.70	2	.719882	1.1386					
	40.10	2	.738212	1.1244					
	59.10	4	.830648	1.0600		47.90	3	.777356	1.0957
	61.15	1	.839692	1.0542					
	64.80	2	.855301	1.0446					
	74.80	3	.894519	1.0214					
	86.00	2	.931820	1.0007		62.30	1	.844050	1.0515
	97.25	1	.961583	0.9852					
	101.30	2	.962272	0.9810					

RELATION OF TUNGSTITE AND HYDROTUNGSTITE

It might be well at this point to indicate the reasons for considering the structure of tungstite and hydrotungstite to be best expressed by the formulae H_2WO_4 and $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$, respectively.

In his attempts to distinguish the two alteration products in the Calacalani material, Professor Moses made a study of their temperatures of dehydration. He determined the loss in weight for each mineral at intervals of 10° from 50° to 250°C . with a final determination at 310° , above which point volatilization occurred. These observations have been plotted in the form of two sets of curves which are reproduced as Figs. 7 and 8. Figure 7 shows the curves for loss of water from 50°C . The total water expelled from the tungstite is slightly above that required by the formula. This was probably adsorbed water and accounts for the small amount of water lost by that mineral below 120° . If the curve for hydrotungstite is examined it will be seen that almost exactly one-half of the water (one molecule) lost is driven off below 120° while above that temperature the curve resembles that of tungstite.

To further check this point, the loss of water of the two minerals above 120° was recalculated to 100% and is shown in Fig. 8. Although the two curves do not coincide, their similarity suggests that the water lost above that temperature is held in the same manner in both minerals. While further study of the dehydration behavior of the two minerals might show this relation more clearly, the data given by Professor Moses are sufficient for purposes of comparison.

This would indicate that the two molecules of water of hydrotungstite are held in different ways. One is loosely held and is driven off at a temperature below 100° while the other is held in the same manner as the single molecule of water in tungstite and is not expelled until the temperature is raised above 120° . On the basis of this evidence the writers would consider the structures as best expressed by H_2WO_4 and $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$.

Further support of this conclusion is furnished by Morely (1930) who carried on similar experiments with the artificial material. He gives no data on the method or temperatures employed in his study but he states: "The evidence therefore clearly points to the formula $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$ for tungstic acid A." (p. 1998); on the basis of his chemical studies described earlier in his paper he concludes: "The results show that two definite compounds exist of composition H_2WO_4 and $\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$, other tungstic acids being mixtures containing several constituents" (p. 1988).

To further check the validity of this conclusion, a sample of hydrotungstite was held at 100°C . for nine days. At the end of this period an

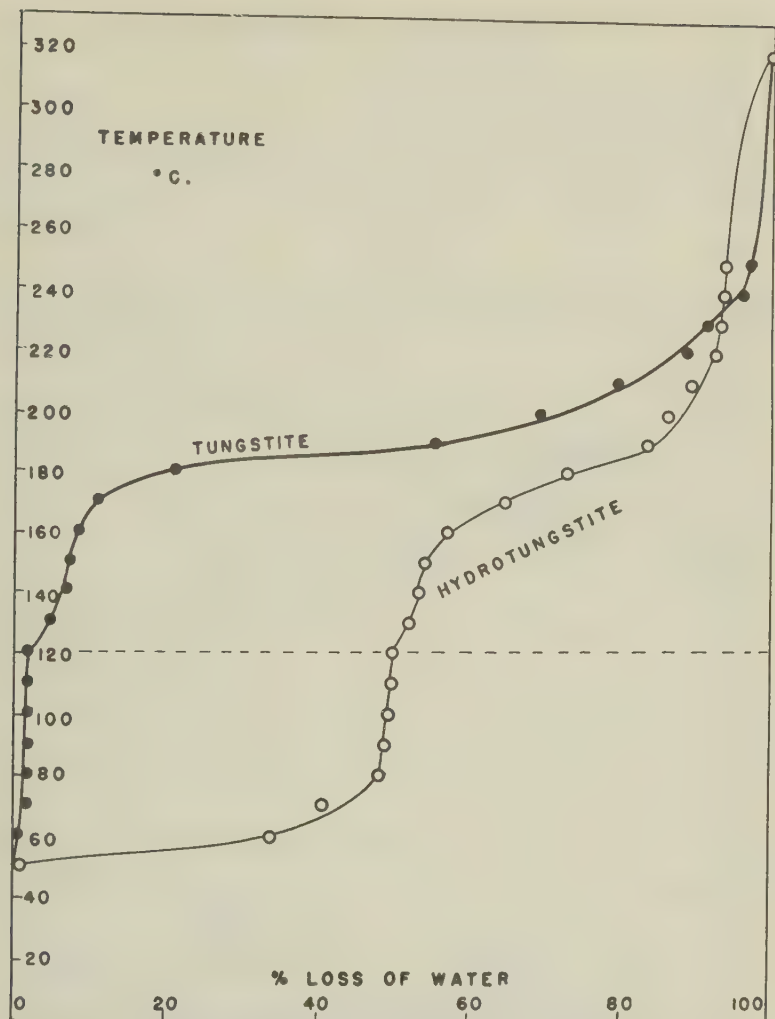


FIG. 7. Curves showing loss of water by tungstite and hydrotungstite in per cent from 50°C.

x-ray pattern was run as shown in Fig. 5D. Careful comparison shows this pattern to agree with patterns of tungstite. Thus the pattern of the heated material indicates that after the loss of the loosely-held molecule of water, the structure has changed from that of hydrotungstite to that of tungstite.

It is likely that the hydrotungstite of the Calacalani deposit has formed as the initial alteration product of the ferberite. The tungstite

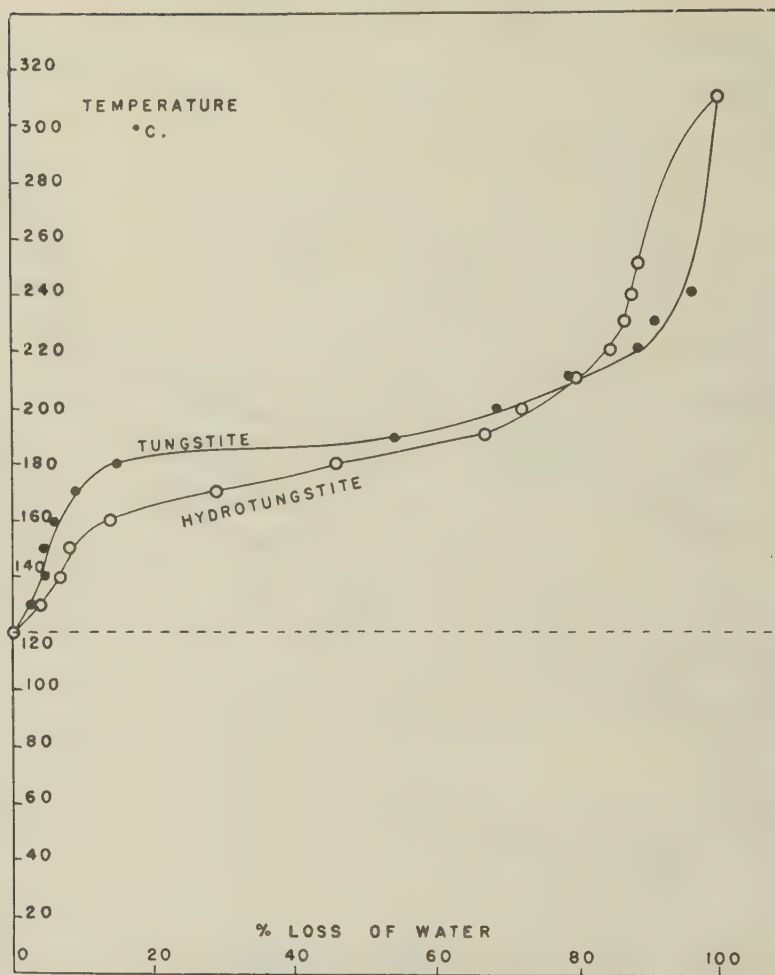


FIG. 8. Curves showing loss of water by tungstite and hydrotungstite in per cent from 120°C.

appears to be later and in many cases seems to have formed from the hydrotungstite. This has been observed on some of the specimens stored in a warm dry room for several years. These have an earthy surface coating of pulverent greenish-yellow tungstite while on breaking the specimen to expose a fresh surface, lustrous green hydrotungstite is found. Whenever tungstite and hydrotungstite are found together in these specimens, the tungstite invariably forms a coating on the hydrotungstite. It may also be observed that the ferberite of those specimens which contain hydrotungstite alone is less altered. Nearly all clusters of hydrotungstite

contain cores of unaltered ferberite, while larger masses of tungstite are often found to be completely free from ferberite.

From the above evidence it is concluded that hydrotungstite is an intermediate mineral of a more hydrous form which may represent a stage in the formation of tungstite. Because of the chemical relationship of the two minerals it seems appropriate to apply the name hydrotungstite to this new mineral.

SUMMARY

Since the major problem involved in this study has been the distinction between the two oxides, it is felt that a tabulated comparison of the

TABLE 5. COMPARISON OF PROPERTIES OF TUNGSTITE AND HYDROTUNGSTITE

Property	Tungstite	Hydrotungstite
1. Composition	H_2WO_4	$\text{H}_2\text{WO}_4 \cdot \text{H}_2\text{O}$
2. Form	Fine rounded aggregates of acicular crystals; earthy masses.	Minute reticulated intergrowths of platy crystals.
3. Color	Yellow; greenish-yellow, yellowish-orange.	Dark green to yellowish-green.
4. Luster	Resinous to earthy.	Vitreous to dull.
5. Sp. gravity	5.517	4.60
6. Hardness	1-2	2
7. Closed tube	Yields water and bleaches.	Yields abundant water, turns yellow, then bleaches.
8. On charcoal	Darkens and volitalizes, no sublimate.	Decrepitates, turns yellow, darkens and volitalizes, no sublimate.
9. Salt of Phosphorus bead.	Blue color due to tungsten.	Blue color due to tungsten.
10. Solubility	Insoluble in acids, soluble in NH_4OH .	Insoluble in acids, soluble in NH_4OH .
11. System	Orthorhombic	Monoclinic (?)
12. Cleavage	Perfect {001}	Imperfect {010}
13. Extinction	Parallel to edge in longitudinal sections and to diagonal in cross sections.	3° measured on {010}.
14. Indices	$\alpha=1.82, \gamma=2.04$	$\alpha=1.70, \beta=1.95, \gamma=2.04$
15. Birefringence	Strong=0.22	Extreme=0.34
16. Absorption	$Z>Y>X$ Z=dark yellow, Y=light yellow, X=colorless.	$Z>Y>X$ Z=dark green, Y=yellow green, X=colorless.
17. Orientation	Optic plane parallel to the long diagonal in cross section. $\text{Bx}_a=\text{X}$ (negative). Crystals length slow.	Optic plane \parallel to {010}. Bx_a about 3° from the \perp to {001}. $\text{Bx}_a=\text{X}$ (negative). Crystals length slow or fast.
18. 2V	Ca 27°	Ca 52°
19. Dispersion	$r < v$	$r < v$

properties of each would be convenient. Such a comparison is given in Table 5.

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TWO NEW TELLURITES OF IRON: MACKAYITE AND BLAKEITE. WITH NEW DATA ON EMMONSITE AND "DURDENITE"

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ABSTRACT

Two new tellurites of iron, mackayite and blakeite, are described, and a third new tellurite is noted. Durdenite of Dana and Wells (1890) from Honduras is shown to be identical with emmonsites of Hillebrand (1885, 1904) from Cripple Creek, Colorado. The name emmonsites is retained for the species. Two new localities for emmonsites, at Silver City, New Mexico, and Goldfield, Nevada, are described. A resumé of the descriptions of mackayite and blakeite follows.

Mackayite is a hydrated ferric tellurite of uncertain formula, perhaps $\text{Fe}_2(\text{TeO}_3)_3 \cdot x\text{H}_2\text{O}$. Tetragonal. Space group probably $I/4acd$. Cell dimensions: $a_0 = 11.70 \pm 0.02$, $c_0 = 14.95 \pm 0.02$; $a_0:c_0 = 1:1.278$ (*x-ray*); $1:1.259$ (morphology). Crystals prismatic $\{001\}$ with $a\{010\}$, $m\{110\}$, $g\{012\}$ and $f\{112\}$; rarely pyramidal $\{112\}$. No cleavage. $H = 4\frac{1}{2}$. $G = 4.86$. Fracture subconchoidal. Luster vitreous. Color peridot- to olive-green and blackish-green. Streak light green. Optically, uniaxial positive (+), with $\omega = 2.19 \pm 0.02$, $\epsilon = 2.21 \pm 0.02$. Faintly pleochroic, with ω yellowish-green, ϵ green. Found sparingly at Goldfield, Nevada, as a secondary product in vugs and seams in silicified rhyolite and dacite, associated with emmonsites, tellurite, alunite, barite, quartz, and the new mineral blakeite. Named for John W. Mackay (1831–1902), a mine operator on the Comstock Lode and benefactor of the Mackay School of Mines.

Blakeite occurs in minute amounts as microcrystalline crusts of a deep reddish-brown color. Contains Fe and Te as the only major constituents but the formula is unknown. Nearly or quite isotropic, with $n = 2.16 \pm 0.02$. Named after William P. Blake (1826–1910), a pioneer geologist and mineralogist of the American southwest.

Emmonsites and mackayite on heating to 750°C . fuse and lose water and the residue gives the *x-ray* powder pattern of artificial anhydrous $\text{Fe}_2(\text{TeO}_3)_3$. Blakeite gives in addition faint lines apparently belonging to admixed FeTeO_4 . *X-ray* powder diffraction data are given for mackayite, blakeite, emmonsites, artificial $\text{Fe}_2(\text{TeO}_3)_3$, and for a new, unnamed, tellurite of iron from Honduras.

INTRODUCTION

The writers recently have had opportunity to examine a large suite of material from Goldfield, Nevada, comprising masses and drusy crusts of emmonsites associated with several seemingly new compounds of iron and tellurium. The material was collected by Mr. C. D. Woodhouse of Santa Barbara, California, to whom the writers are indebted for a loan of specimens. Information regarding the details of the occurrence and some additional specimens were supplied by Mr. Hatfield Goudy of Jamestown, California.

* Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 267. Prepared in collaboration with the Department of Geology and Mineralogy, The American Museum of Natural History.

Hitherto, four compounds of iron and tellurium have been reported as occurring in nature. These are durdenite of Dana and Wells (1890), emmonsite of Hillebrand (1885), a speculative substance, ferrotellurite, described by Genth (1877), and an ill-defined, unnamed, material from Cripple Creek, Colorado, analyzed by Knight (1894). The characterization of these minerals is not as complete as might be desired, especially where the description of possibly new minerals of similar composition is concerned. Type specimens of durdenite and emmonsite were obtained for the purpose of verifying the physical and other characters and for getting the *x*-ray powder diffraction patterns. Specimens of the minerals described by Genth and by Knight were not available. A summary of the present knowledge of the four substances mentioned follows.

EMMONSITE

Two localities for emmonsite have been described, but there is no certainty that the material from the two are identical. The mineral was originally reported by Hillebrand in 1885 from a locality near Tombstone, Arizona. The substance, for which scant physical and crystallographic data are available, occurred very sparingly as yellowish-green scales and patches in a hard brownish gangue composed of an intimate mixture of cerussite, quartz, and a brown oxygenated compound of iron and tellurium that was not further described. Optically, the material is stated by Cross, cited in Hillebrand, to be:

TABLE 1. ANALYSES OF EMMONSITE

	1.	2.	3.	4.	5.	6.	7.	8.
Fe ₂ O ₃	[20.02]	[20.10]	[21.30]	[20.30]	22.67	22.81	22.79	25.41
Fe	14.00	14.06	14.90	14.20				
TeO ₂	[74.80]	[74.01]	[73.90]	[74.00]	70.83	71.80	70.20	62.34
SeO ₂								2.12
Te	59.77	59.15	59.05	59.14				
H ₂ O+ } H ₂ O- }	3.28				4.68 0.34	4.82	0.21	10.13
P ₂ O ₅								
Al ₂ O ₃						0.58	0.54	
ZnO				1.94				
CaO				0.56				
Total	[98.10]	[94.11]	[95.20]	[96.80]	98.52	100.01	93.74	100.00

Analyses 1, 2, 3 and 4 by Hillebrand (1885) were made on material from Tombstone, Arizona. Oxide per cent calculated from determination of element. Analyses 5, 6 and 7 by Hillebrand (1904) were made on material from Cripple Creek, Colorado. Analysis 8 by Wells (cited by Dana and Wells (1890)) on "durdenite" = emmonsite is from Honduras. Recalculated to 100 after deduction of 23.89 per cent insoluble material.

"System probably monoclinic. The good cleavage plane may represent the clinopinacoid, for while extinction in it never seems to take place exactly parallel to the longer axis of the fragments, all those which allow of tests perpendicular to the cleavage plane do extinguish parallel to its trace. Plates parallel to the cleavage generally show that two directions of less perfect cleavage exist, which are nearly at right angles to each other. Extinction 8° to 12° from one of these directions. Refraction strong. Pleochroism very slight. Position of optical axes not determinable."

Three partial analyses were made upon material admixed with 3–5 per cent quartz and a small per cent of the brown mineral mentioned. A fourth analysis was made on 150 mg. of material containing quartz, gypsum (?) and calamine but none of the brown mineral. These analyses are cited in columns 1–4 of Table 1. Qualitative chemical tests indicated that the mineral was essentially a ferric tellurite and not a ferrous tellurate. In a later note, Hillebrand (1890) gave a new determination of the water (4.2 per cent) and re-determined the ratio of $\text{Fe}_2\text{O}_3:\text{TeO}_2$ as 1:3.75. One gathers from Hillebrand's remarks that all of his material from this locality was used up in the chemical work.

In 1904, Hillebrand described an iron tellurite from the W. P. H. mine at Cripple Creek, Colorado, which was provisionally regarded as emmonsite. The mineral occurred in green mammillary forms associated with tellurite and partly oxidized calaverite. Lindgren and Ransome (1906) state that this, or a similar mineral, is probably generally present in oxidized ores at Cripple Creek. The mineral melts at a low heat to a red-brown liquid as does the original emmonsite. The optical properties are described by Schaller, cited in Hillebrand (1904), as follows:

"There are two cleavages, one parallel to $b(010)$ and another parallel to a form in the orthozone. Axial plane parallel to $b(010)$. Bx_a perpendicular to a cleavage face in the orthozone. The extinction on the clinopinacoid is inclined 25° to 30° to the vertical axis. $2E$ is approximately 40° . Double refraction medium, and the mineral is non-pleochroic."

Additional optical properties determined on the original specimen are given by Larsen (1921, 1934), as follows:

Optically negative (–). $2V=20^{\circ}\pm$, Dispersion $r>v$, strong. X is nearly \perp to a cleavage. $X=1.95\pm 0.02$, $Y=b=2.09\pm 0.02$, $Z=2.10\pm 0.02$.

Hillebrand made three partial analyses on portions of from 150 to 200 mg. each of the material from Cripple Creek. These analyses, after deducting 22.44 per cent of gangue, are as given in columns 5–7. The mean of the four analyses of the material from Tombstone corresponds to the ratio $\text{Fe}_2\text{O}_3:\text{TeO}_2:\text{H}_2\text{O}=1:3.63:1.42$, and the mean of the three analyses of the material from Cripple Creek corresponds to the ratio $\text{Fe}_2\text{O}_3:\text{TeO}_2:\text{H}_2\text{O}=1:3.12:1.85$. Little weight can be placed on these ratios considering the small size of the analyzed samples and the known presence of impurities. Analysis 8 on durdenite, a mineral now shown to be identical with

emmonsites, gives the ratio $\text{Fe}_2\text{O}_3:(\text{Te,Se})\text{O}_2:\text{H}_2\text{O}=1:2.59:3.54$. The formula $\text{Fe}_2(\text{TeO}_3)_3 \cdot 2\text{H}_2\text{O}$ probably best represents the composition of emmonsites.

The original analyzed specimen (U.S.N.M. 86846) of the so-called emmonsites from Cripple Creek was made available for examination through the courtesy of Mr. E. P. Henderson of the U. S. National Museum. The *x*-ray powder diffraction pattern differs entirely from those of artificial $\text{Fe}_2(\text{TeO}_3)_3$, mackayite, and blakeite, but is identical with that of durdenite. The spacing data are given in Table 3 and the pattern is shown in Fig. 5. On heating, the material lost water and fused. The residue gave the *x*-ray pattern of artificial anhydrous $\text{Fe}_2(\text{TeO}_3)_3$. In view of the uncertainty as to the true nature of the original emmonsites from Tombstone and the improbability that more complete data on this material will be forthcoming, since there appear to be no specimens extant, it seems advisable to attribute the properties of the material from Cripple Creek to the species. The available data suggest that the two materials were identical.

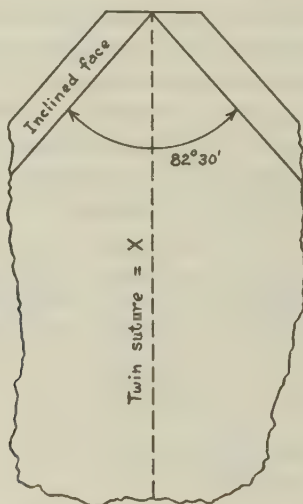


FIG. 1. Microscopic twinned crystal of emmonsites.

Two new occurrences of emmonsites were found in the course of the present study. Emmonsites occurs rather abundantly in oxidized material at Goldfield, Nevada, associated with tellurite and two new minerals, mackayite and blakeite, described beyond. The mineral appears variously, as fibrous crusts with a botryoidal surface, as drusy crusts of mi-

nute indistinct crystals, in dense and compact microcrystalline masses which grade into the matrix and, rarely, as radial groups of rough, serrated, acicular crystals. The matrix is brecciated, ferruginous and silicified rhyolite and dacite. The color of the mineral is bright green, inclining towards pale green and yellowish-green in some of the dense masses. Optically, this material had $X = 1.962 \pm 0.004$ = light green, $Z = 2.12 \pm 0.02$ = darker green, and otherwise corresponded to the emmonsite from Cripple Creek. A sketch of a microscopic twin crystal is shown in Fig. 1; X is parallel to the twin suture.

The minute crystals of the druses and radial aggregates are in part outwardly stained or altered to a brownish tint of color. This occurrence appears to have been known for some time, inasmuch as specimens labelled emmonsite from Goldfield, Nevada, were purchased by the Harvard Mineralogical Museum from a dealer in 1930. Ransome (1909) stated that greenish-yellow and canary-yellow selenian ferric tellurites occur as fibrous, lichen-like rosettes in oxidized ore at several localities in the Goldfield district.

Emmonsite also occurs near Silver City, New Mexico, as green botryoidal crusts in crevices in quartz- and pyrite-rich vein material. The mineral has been derived by the alteration of native tellurium, with which it is usually associated. The specific gravity was determined on the microbalance as 4.52.

"DURDENITE"

Durdenite was originally described by Dana and Wells in 1890, who observed greenish-yellow small, mammillary masses associated with selenian tellurium on specimens from the El Plomo mine in the Ojojoma district, Tegucigalpa, Honduras. The analysis by Wells is cited in column 8 of Table 1. The optical constants of a mineral from the type locality ascribed to durdenite were later published by Larsen (1917, 1921). A second occurrence of this mineral in Calaveras County, California, was then established by Larsen by optical measurements. Larsen's optical data follow:

Material from Honduras is optically negative (−) with $2V_{Na} = 22^\circ \pm 1^\circ$ and strong dispersion $r > v$. X is perpendicular to a face or cleavage and two other perfect cleavages, possibly faces, occur normal to this one with an angle of 72° between them. Y bisects the acute angles between the cleavages. Strongly pleochroic, with absorption $Z > Y > X$. $X = 1.702$, nearly colorless; $Y = 1.955$, pale greenish-yellow; $Z = 1.965$, pale sulfur yellow (indices ± 0.005). Probably orthorhombic.

Material from California is optically negative (−) with $2V_{Na} = 24^\circ \pm 2^\circ$ and has very strong dispersion $r > v$. The grains tend to lie on a cleavage normal to X . $X = 1.710 \pm 0.005$, $Y = 1.94 \pm 0.01$, $Z = 1.95 \pm 0.01$.

Durdenite also was said by Lindgren and Ransome (1906) to occur at Cripple Creek, Colorado, but details of the occurrence are lacking.

A specimen of durdenite from the type locality in Honduras which answered to the original description in every particular was obtained for study from the collection of the American Museum of Natural History (Spec. no. 16832). Two different minerals were present on the specimen. One was a greenish-yellow botryoidal substance which corresponds to the mineral described by Dana and Wells and is their durdenite. The x -ray powder diffraction pattern of this mineral corresponds exactly with that of Hillebrand's emmonsite from Cripple Creek. The following optical data were obtained. Biaxial negative, with small $2V$; $X=1.962\pm0.002$, Z slightly greater than 2.09; strong dispersion with $r>v$. Weakly pleochroic in green with absorption $Z>X$. These data correspond to those given by Larsen (1921) for type emmonsite from Cripple Creek and verified independently by the writers on material from this locality. The chemical analyses of the minerals from the two localities are very similar, and differ principally in the amount of water reported. This discrepancy can carry little weight in view of the nature of the analyses. In light of these facts the identity of durdenite with emmonsite must be accepted. The question of priority of name is vexing, but it appears desirable to retain the name emmonsite for the species.

The second of the two minerals on the Honduras specimens was observed by Dana and Wells and was tentatively identified by them as tellurite. The optical properties of this mineral as determined here correspond exactly with those given by Larsen (1921) for "durdenite" and cited above. Larsen mistook the mineral for the durdenite, which it overlays. The mineral forms tiny, thin, orthorhombic plates with a honey-brown color and an adamantine luster. A spectrographic analysis, kindly made by Dr. Rockwell Kent, Jr., on a Baird two meter grating instrument, revealed the presence of only Fe and Te in significant amounts, with traces of Cu, Ag, Mg, Ca, V, Al, Si and Sb. Selenium may be present, however, in appreciable amounts. The x -ray powder pattern and the optical constants of the mineral are entirely different from those of the other iron tellurites and there is no question but that the mineral is a new and distinct species. It is intended to give a formal description of this mineral at a future time. The x -ray spacing data are listed in Table 3 and the pattern is shown in Fig. 5.

FERROTELLURITE

The name ferrotellurite was given by Genth in 1877 to microscopic tufts of a straw- to lemon-yellow mineral found with tellurite and native tellurium at the Keystone mine, Magnolia district, Boulder Co., Colo-

rado. Qualitative tests showed the presence of iron and tellurous oxide, and the mineral was suggested to be ferrous tellurate, FeTeO_4 . Later, Genth stated in a private communication to E. S. Dana (1892) that it was not impossible that the substance was tellurite colored yellow by a salt of iron. This substance hardly seems worthy of further record in view of the complete lack of definitive characters.

UN-NAMED TELLURITE OF IRON OF KNIGHT

This substance, from Cripple Creek, Colorado, was analyzed by Knight in 1894. The description states only that the substance formed light brown amorphous masses with a dull luster and a bright yellow streak. The hardness is given as between 3 and 4. The material occurred intimately admixed with calaverite. The composition of the HCl-soluble portion of a bulk sample of the mixture, amounting to about 25 per cent of the total, is given in column 1, below. A second, similar analysis of another specimen is given in column 2. The water represents the ignition loss between 100° and 160° .

	Fe_2O_3	TeO_2	H_2O	Total
1.	30.27	68.05	1.68	100.00
2.	35.44	62.79	1.77	100.00

The average of these analyses is not far from the ratio $2\text{Fe}_2\text{O}_3 \cdot 4\text{TeO}_2 \cdot 1\text{H}_2\text{O}$, but this is due to chance as likely as not. If the Te determination is high, as would seem probable, the substance might be a hydrated ferric tellurite. In any case, this substance, like ferrotellurite, lacks definitive characters and hardly could again be recognized with certainty from the existing description.

MACKAYITE

The new mineral described here under the name mackayite was found in specimens from two deposits in Goldfield, Nevada. The better crystals came from a small shaft between the Jumbo and Clermont mines, known as the McGinnity shaft. The tellurites came from the 90 foot level, which is now inaccessible. Crusts of smaller crystals occur on specimens from the Sheets-Ish lease of the Mohawk mine. Mackayite occurs in small, well developed crystals in vugs and seams in silicified rhyolite and dacite, much of which has been converted to a silicified fault breccia. It is associated with abundant crusts and masses of emmonsite, white powdery masses of tellurite, crystals of alunite, quartz and barite, limonite and a few reddish-brown crusts of a second new mineral, blakeite, described beyond. Mackayite is extremely rare and none of the specimens seen were very rich; most of them showed but a few isolated crystals.

At the instance of Mr. C. D. Woodhouse, the writers propose the name mackayite for the species after John W. Mackay (1831–1902), a mining operator who in a few years amassed a great fortune on the Comstock Lode, Nevada. The name is intended to recognize Mackay's financial endowment of the School of Mines of the University of Nevada.

X-Ray Crystallography

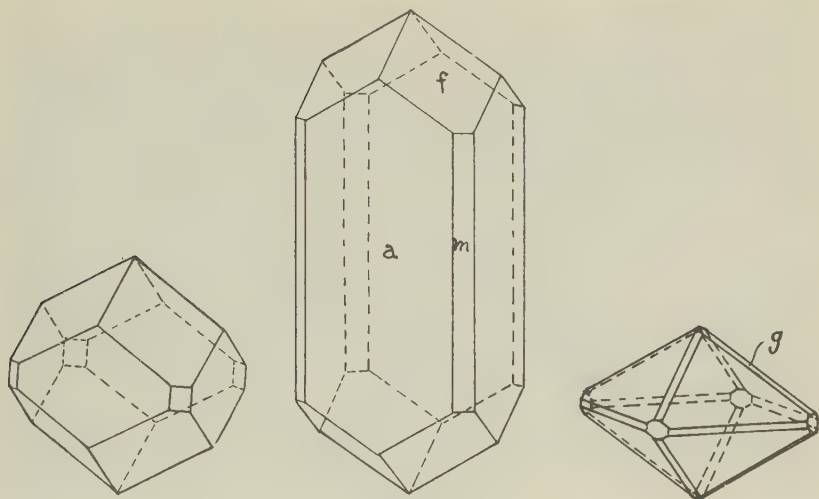
The *x*-ray powder pattern of mackayite is entirely distinct from the patterns of the other known iron tellurites. The spacing data are given in Table 3 and the pattern is represented in Fig. 5. A Weissenberg *x*-ray study was made of a crystal fragment similar in habit to Fig. 2. Rotation 0- and *n*-layer photographs were taken about [001] and rotation and 0-layer photographs about [100] and [110]. The symmetry of the films is entirely in accordance with tetragonal centrosymmetry, $4/mmm$. The cell dimensions as calculated from high order axial reflections on the 0-layer photographs are:

$$a_0 = 11.70 \pm 0.02, c_0 = 14.95 \pm 0.02; a_0:c_0 = 1:1.278.$$

The space group probably is $I/4acd$, which would uniquely fix the point-symmetry as ditetragonal-dipyramidal.

Morphology

Mackayite crystals are well developed and are consistent with ditetragonal-dipyramidal symmetry. No general forms are present. The habit is simple, and varies somewhat in different crystals. Usually all crystals on a single specimen have the same habit. The commonest crystals are those of Fig. 2. Elongated prismatic crystals like those of Fig. 3 were observed on but one specimen. The crusts of exceedingly minute crystals, such as those of the Sheets-Ish lease, seem invariably to be like those of Fig. 4. The form *g* {012} always is exceedingly narrow, giving no definite signal but rather just a brilliant reflection when observed on the goniometer. On most crystals *a* {100} was a broad face, showing some vertical striation, and tending to give a multiple signal in the zone [001]; *m* {110} is narrow, and gives better signals. *f* was the only face that could be measured on the terminations and it was often not smooth enough to give satisfactory reflections, especially in crystals of any size. In general, because of the character of the reflections, the data from the goniometric measurements is probably less accurate than those given by the *x*-ray measurements. An angle table is given in Table 2. The crystals reached a maximum of 1 mm. in length but most were far smaller.



FIGS. 2, 3 and 4.

TABLE 2. ANGLE TABLE FOR MACKAYITE
 Tetragonal; ditetragonal dipyramidal— $4/m\ 2/m\ 2/m\ (?)$
 $a:c=1:1.259$; $p_0:r_0=1.259:1$

Form	ϕ	ρ	Λ	\overline{M}
<i>a</i> 010	0°00'	90°00'	90°00'	45°00'
<i>m</i> 110	45 00	90 00	45 00	90 00
<i>g</i> 012	0 00	32	90 00	68
<i>f</i> 112	45 00	41 41	61 57	90 00

Chemistry

A pure sample of about 150 mg. total weight was separated from about a half kilogram of gangue by a process of magnetic and heavy liquid separation followed by hand picking. Unfortunately a projected analysis cannot be undertaken at the present time due to the diversion of the analyst and laboratory facilities to other work. Qualitative chemical tests revealed the presence of Fe, Te and H₂O as major constituents. A spectrographic examination indicated that only Fe and Te were present in significant amounts. On heating, mackayite fuses, loses water, and the residue gives the *x*-ray powder pattern of artificial anhydrous Fe₂(TeO₃)₃. Mackayite is similar to emmonsite in this respect. Mackayite is believed to be a hydrated ferric tellurite, either polymorphous with emmonsite, or, more probably, having the same Fe to Te ratio as that species but differing in the content of water of crystallization.

Physical Properties

Mackayite is not cleavable. The fracture is subconchoidal. Brittle. The mineral distinctly scratches fluorite but does not scratch apatite so that the hardness may be given as $4\frac{1}{2}$. The specific gravity was determined on the microbalance as 4.86. This value may be somewhat in error inasmuch as the determination was made on a very small sample of the coarse powder by means of a supplementary wire basket. The luster is vitreous. The color of the mineral varies from light peridot-green to olive- and brownish-green. Some of the larger crystals are greenish-black in color. The streak is light green. Transparent. In crushed grains under the microscope mackayite is greenish-yellow to yellowish-green in color. Optically, the substance is uniaxial positive (+). The indices of refraction were determined in sulfur-selenium melts as $\omega=2.19$, $\epsilon=2.21$ (both ± 0.02). The mineral is very faintly pleochroic with ϵ yellow-green and ω green.

BLAKEITE

The new mineral here described under the name blakeite occurs very sparingly as microcrystalline crusts of a rich brown or deep reddish-brown color. The crusts rest upon unaltered emmonsite crystals. Neither the specific gravity nor the hardness could be determined. The powder easily abrades gypsum and the specific gravity is greater than 3.1. The material is rather harsh to the touch and readily breaks down to a coarse powder. The streak is yellowish-brown while the luster of the aggregate is dull. Under the microscope blakeite appears as brown to golden-yellow and yellowish-brown transparent grains that often present a semblance of cubic outline. No evidence of admixture was seen. The material is either nearly or quite isotropic; some grains are very faintly birefringent, but it is not certain if this is a property of the mineral or is an anomalous feature. The index of refraction, measured in sulfur-selenium melts, is 2.16 ± 0.02 .

A spectrographic examination revealed the presence only of Te and Fe. In comparison to emmonsite and mackayite the mineral contains less Te and more Fe. The x-ray powder diffraction pattern differs entirely from those of the other Fe-Te minerals. The spacing data are given in Table 3 and the pattern is represented in Fig. 5. On heating, blakeite does not fuse or change color. The heated material gives a new x-ray pattern, that represents a mixture of anhydrous ferric tellurite with a substance that appears to be ferric tellurate. A pure sample of approximately 60 milligrams weight was prepared and it is hoped that an analysis can be made at some future date. The mineral is provisionally classed as an anhydrous ferric tellurite, but it is possible that the Te is present in two valences. It is of interest to note that earthy brown

oxygenated compounds of iron and tellurium were reported by Hillebrand (1885) from Tombstone, Arizona, and by Knight (1894) from Cripple Creek, Colorado.

The name blakeite is given in honor of William P. Blake (1826-1910), a pioneer geologist and mineralogist of the American southwest.¹ Blake was the first person to recognize the occurrence of tellurium minerals in California.

PARAGENESIS OF MACKAYITE AND BLAKEITE

Mackayite and blakeite formed in the oxidized zone of the McGinnity and Sheets-Ish ledges. Mr. Hatfield Goudy says* that a crosscut intersecting the same ledge at 120 feet shows only native tellurium and pyrite. There can be little question but that all of the ferric tellurites formed as a result of the alteration of those primary minerals. One specimen showed native tellurium solidly embedded in quartz, while in the fissures were crystals of mackayite and emmonsite.

The sequence of mineralization would appear to be about as follows. The rock, a rhyolite or dacite porphyry, was brecciated and silicified. The quartz phenocrysts of the original rock are still present apparently unaffected in a fine-grained siliceous ground mass. At the same time, small amounts of tellurium and pyrite together with scattered crystals of barite and alunite were deposited. Barite seems to have been a little earlier than the alunite. The solutions which brought about this alteration presumably were ascending hypogene. All of the subsequent alteration, on the other hand, is clearly the result of descending supergene solutions. The age relationship between emmonsite and mackayite is very confusing and it seems likely that formation was almost simultaneous, with one or the other forming dependent upon local conditions. Specimens were seen in which mackayite crystals had commenced to alter to emmonsite on the surface, and on the other hand, small radiating rosettes of emmonsite were seen to be slightly corroded while mackayite in the same specimen was quite fresh. Presumably some change in the character of the solutions could function to make one or another of the two minerals stable at the same time in different portions of the vein. Though the emmonsite was corroded and the mackayite fresh in one specimen, in another specimen small spheres of emmonsite were perched on a type 1 mackayite crystal. Blakeite is clearly later than either of the two; in the best specimen it formed a thick rather loose layer over some of the best unaltered emmonsite crystals which were seen. Thin limonite films were also seen to coat the tellurites, but other limonite stained sur-

¹ An appreciation of Blake's life and work is given in the *Bull. Geol. Soc. Am.*, 22, 36-47 (1911).

* Personal communication.

faces were flecked with mackayite and emmonsite, so this substance can be considered a mineral of all stages of the oxidation.

ARTIFICIAL FERRIC TELLURITE AND FERRIC TELLURATE

Ferric tellurite was prepared by the standard method of adding a weakly acid solution of ferric chloride to a solution of sodium tellurite in the theoretical proportions. The voluminous brown precipitate was allowed to stand in contact with the faintly acid mother liquid for 48 hours. The precipitate, after filtration and washing, dried out to a hard hydrous gel that did not give an x -ray diffraction pattern. The material gave a rather diffuse pattern with a heavy background after heating to 510°C . The pattern became quite clear and sharp when the material was heated at 750° . The substance did not fuse. The residue obtained by fusing emmonsite and mackayite gives the x -ray pattern of this substance. The spacing data are given in Table 3 and the pattern is shown in Fig. 5. Under the microscope the artificial material appeared homogeneous, and was composed of a fine-grained yellowish-brown to yellow and greenish-yellow substance with strong birefringence and very high indices. An attempt was made to prepare ferrous tellurite by starting with ferrous sulfate and sodium tellurite but the product oxidized very rapidly to ferric tellurite.

Efforts to prepare ferric tellurate were not entirely successful. The substance was precipitated by the reaction of ferric chloride and sodium tellurate in water solution in the required proportions. The air-dried gel did not give an x -ray pattern, and material heated at 450° gave only a very faint pattern that was badly fogged. A sample heated at 750° when examined under the microscope was found to consist of a mixture of two substances: a yellowish-green material with strong birefringence that appeared to be identical with ferric tellurite, and a material forming flat hexagonal plates of a deep reddish-brown color. The latter substance may be ferric tellurate. An x -ray photograph of the mixture showed almost all of the lines of ferric tellurite together with a number of additional lines. The stronger ones of these extra lines were present in the pattern of the residue obtained by heating blakeite to 750° . The presence of ferric tellurite in the heated sample of artificial ferric tellurate probably is due to the reduction of the tellurate at high temperatures. Lenher and Wolessensky (1913) have shown that the alkali tellurites oxidize to tellurates when heated to about 450° but that the alkali tellurates are reduced to tellurites when heated above 450° to red heat. Only half of the Te in the alkali ditellurites appears to oxidize on heating.

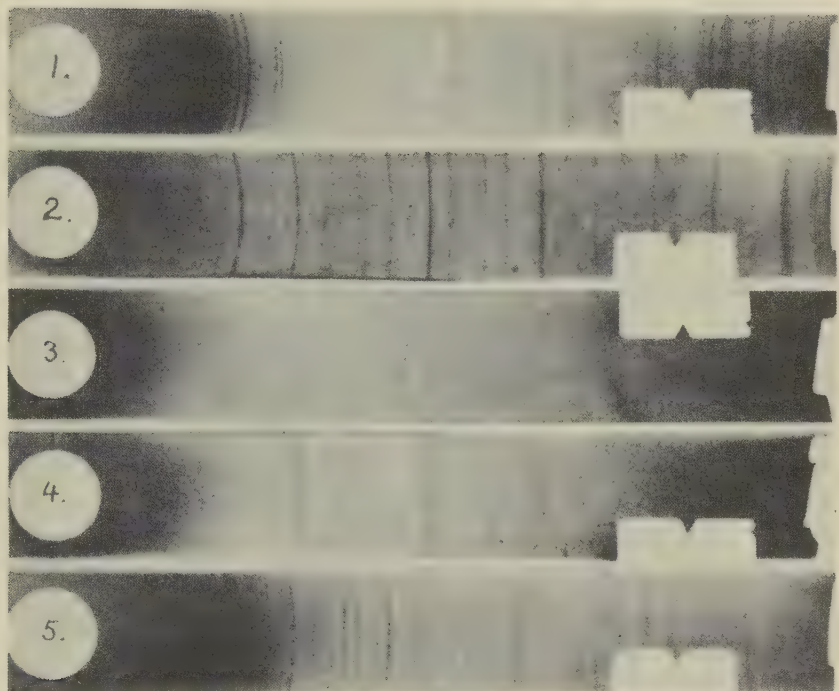


FIG. 5. X-ray powder photographs of iron tellurites. Fe radiation, unfiltered.

1. Mackayite. Goldfield, Nevada.
2. Artificial $\text{Fe}_2(\text{TeO}_3)_3$.
3. Emmons site. Goldfield, Nevada. Identical patterns are given by "durdenite" from Honduras and emmons site from Cripple Creek.
4. Blakeite. Goldfield, Nevada.
5. New, undescribed iron tellurite from Honduras.

TABLE 3. X-RAY SPACING DATA FOR IRON TELLURITES. Fe RADIATION.
SPACINGS BELOW 1.47 ARE NOT LISTED.

Enmonsite		Mackayite		Blakeite		Artificial $\text{Fe}_2(\text{TeO}_3)_3$		New Fe-Te Mineral (Hondura)	
<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>	<i>d</i>	<i>I</i>
5.80	7	6.18	1	5.44	5	4.56	1	7.83	2
4.05	6	5.57	1	4.20	5	4.12	3	7.31	2
3.68	8	5.46	1	3.71	1	3.61	1	7.13	5
3.62	6	5.07	1	3.51	1	3.27	9	6.32	1
3.56	6	4.94	7	3.33	7	2.79	2	5.74	9
3.47	1	4.08	1	3.00	10	2.72	1	3.92	3
3.39	3	3.93	1	2.88	1	2.66	1	3.75	1
3.29	4	3.74	6	2.79	1	2.54	8	3.70	2
3.13	10	3.64	2	2.69	3	2.32	3	3.57	6
3.06	2	3.50	3	2.54	9	2.29	1	3.40	2
2.97	1	3.31	8	2.45	4	2.23	3	3.34	10
2.90	2	3.16	10	2.29	5	2.06	2	3.23	7
2.86	9	3.08	1	2.26	1	2.02	2	3.05	4
2.76	1	2.99	1	2.22	2	1.88	3	2.98	4
2.69	8	2.93	5	2.19	2	1.87	1	2.94	1
2.62	2	2.89	5	1.93	1	1.85	1	2.86	4
2.51	9	2.77	6	1.91	5	1.80	1	2.79	4
2.48	3	2.71	7	1.87	1	1.71	10	2.75	1
2.43	1	2.61	4	1.82	1	1.63	4	2.64	2
2.38	1	2.58	2	1.75	2	1.61	1	2.57	1
2.29	7	2.50	1	1.72	8	1.54	1	2.54	5
2.25	3	2.47	6	1.69	3	1.52	4	2.40	1
2.21	6	2.44	1	1.66	3	1.49	1	2.37	2
2.17	1	2.38	1	1.57	1	1.46	4	2.35	2
2.13	1	2.29	1	1.56	2	1.39	1	2.31	2
2.05	4	2.21	7	1.50	6	1.37	6	2.28	2
2.01	1	2.11	2	1.45	2	1.27	3	2.21	2
1.98	4	2.06	5	1.39	1	1.22	1	2.12	7
1.95	7	2.03	1	1.37	1	1.18	5	2.06	3
1.93	1	1.91	5	1.29	1	1.15	1	2.03	3
1.88	4	1.86	3	1.15	1	1.11	5	1.99	1—
1.85	6	1.85	4			1.08	3	1.97	1—
1.83	1	1.81	2			1.07	1	1.93	4
1.81	1	1.79	2			1.05	7	1.87	8
1.80	8	1.78	4					1.85	1
1.75	2	1.73	4					1.76	1
1.73	2	1.70	2					1.75	6
1.71	1	1.69	4					1.72	1
1.69	1	1.66	1					1.70	3
1.68	1	1.64	1					1.66	3
1.66	2	1.61	9					1.63	1
1.64	2	1.60	3					1.59	5
1.63	1	1.58	5					1.55	3
1.58	2	1.56	1					1.54	1—
1.57	2	1.53	1					1.52	3
1.55	1	1.52	4					1.49	2
1.54	1	1.50	1					1.47	3
1.52	1	1.49	4						
1.47	2	1.47	1						

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VECTOR FORMULAS FOR IDENTIFICATION OF TWINNED LATTICES

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When the reciprocal lattice vectors for planes in a lattice are known, the reciprocal lattice vectors for the twins of these planes (by reflection, rotation or inversion) may be found with the aid of simple vector formulas which are derived in the following report. The vectors are often (as in the case of location by Laue diagrams) most easily designated in terms of spherical coordinates. The transformation equations necessary for such cases are given in the fourth section of this paper.

Twinning by Reflection Across a Lattice Plane

Consider the reflection in a plane $(h_0k_0l_0)$ of another plane (hkl) . In Fig. 1, \mathbf{B}^* represents the vector¹ from the origin to the reciprocal lattice point $(h_0k_0l_0)$, and is, therefore, normal to the $(h_0k_0l_0)$ plane. Similarly, \mathbf{A}^* is the reciprocal lattice vector for the plane (hkl) . The reflection of \mathbf{A}^* in the plane $(h_0k_0l_0)$ is the reciprocal lattice vector \mathbf{X}^* of (\underline{hkl}) , i.e. (hkl) in twinned position.

$$\begin{aligned}\mathbf{X}^* &= \mathbf{A}^* + \mathbf{M}^* \\ \mathbf{M}^* &= -2 \frac{\mathbf{A}^* \cdot \mathbf{B}^*}{|\mathbf{B}^*|^2} \mathbf{B}^* = -2 \frac{\mathbf{A}^* \cdot \mathbf{B}^*}{B^{*2}} \mathbf{B}^*.\end{aligned}$$

Therefore,

$$\mathbf{X}^* = \mathbf{A}^* - 2 \frac{\mathbf{A}^* \cdot \mathbf{B}^*}{B^{*2}} \mathbf{B}^*.$$

In terms of the indices and the fundamental reciprocal lattice vectors $\mathbf{a}^*, \mathbf{b}^*, \mathbf{c}^*$,

$$\begin{aligned}\mathbf{A}^* &= h\mathbf{a}^* + k\mathbf{b}^* + l\mathbf{c}^* \\ \mathbf{B}^* &= h_0\mathbf{a}^* + k_0\mathbf{b}^* + l_0\mathbf{c}^* \\ \mathbf{A}^* \cdot \mathbf{B}^* &= hh_0a_0^{*2} + kk_0b_0^{*2} + ll_0c_0^{*2} + (hk_0 + kh_0)\mathbf{a}^* \cdot \mathbf{b}^* + (hl_0 + lh_0)\mathbf{a}^* \cdot \mathbf{c}^* \\ &\quad + (kl_0 + lk_0)\mathbf{b}^* \cdot \mathbf{c}^* \\ B^{*2} &= h_0^2a_0^{*2} + k_0^2b_0^{*2} + l_0^2c_0^{*2} + 2h_0k_0\mathbf{a}^* \cdot \mathbf{b}^* + 2h_0l_0\mathbf{a}^* \cdot \mathbf{c}^* + 2k_0l_0\mathbf{b}^* \cdot \mathbf{c}^*.\end{aligned}$$

If the lattice is cubic, these expressions will simplify to

$$\begin{aligned}\mathbf{A}^* \cdot \mathbf{B}^* &= (hh_0 + kk_0 + ll_0)a_0^{*2}, \\ B^{*2} &= (h_0^2 + k_0^2 + l_0^2)a_0^{*2}\end{aligned}$$

and

$$\mathbf{X}^* = \mathbf{A}^* - 2 \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} \mathbf{B}^*.$$

¹ All starred vectors are vectors which are most conveniently expressed in terms of reciprocal lattice coordinates.

Since only the direction of \mathbf{X}^* is of interest and not its actual length, the unit cell edge in the reciprocal lattice may be taken as unity ($a_0^* = 1$), in which case the reciprocal lattice components of \mathbf{A}^* , \mathbf{B}^* and \mathbf{X}^* are the corresponding indices. (This holds only for the cubic case. The "indices" of \mathbf{X}^* are not necessarily integers.)

Written in terms of components along the axes of any Cartesian coordinate system, the expression for \mathbf{X}^* becomes

$$X_x^* = A_x^* - 2 \frac{hk_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} B_x^*$$

with similar expressions for X_y^* and X_z^* .

Twinning by Rotation Around a Lattice Row

Consider the rotation of a plane (hkl) around the row $[u_0v_0w_0]$ as axis of rotation. In Fig. 2, \mathbf{B} represents the vector from the origin to the point $[u_0v_0w_0]$ and is therefore directed along the axis of rotation. \mathbf{A}^* is the reciprocal lattice vector for the plane (hkl) and is therefore perpendicular to that plane. \mathbf{X}^* is the reciprocal lattice vector for $(\bar{h}\bar{k}\bar{l})$ ((hkl) in twinned position) and is located by rotating \mathbf{A}^* through an angle, α , around \mathbf{B} . From the figure

$$\mathbf{X}^* = \mathbf{N}^* + \mathbf{L}^*$$

$$\mathbf{N}^* = \frac{\mathbf{A}^* \cdot \mathbf{B}}{|\mathbf{B}|} \frac{\mathbf{B}}{|\mathbf{B}|} = \frac{\mathbf{A}^* \cdot \mathbf{B}}{B^2} \mathbf{B}$$

$$\mathbf{L}^* = \mathbf{S}^* + \mathbf{T}^*.$$

But $|\mathbf{L}^*| = |\mathbf{K}^*|$, so

$$\mathbf{S}^* = \mathbf{K}^* \cos \alpha$$

$$\mathbf{T}^* = |\mathbf{K}^*| \sin \alpha \frac{\mathbf{B} \times \mathbf{K}^*}{|\mathbf{B} \times \mathbf{K}^*|}.$$

But

$$\mathbf{K}^* = \mathbf{A}^* - \mathbf{N}^* = \mathbf{A}^* - \frac{\mathbf{A}^* \cdot \mathbf{B}}{B^2} \mathbf{B}$$

and so

$$\begin{aligned} \mathbf{B} \times \mathbf{K}^* &= \mathbf{B} \times \mathbf{A}^* \\ |\mathbf{B} \times \mathbf{K}^*| &= |\mathbf{B}| |\mathbf{A}^*| \sin \beta. \end{aligned}$$

Also

$$|\mathbf{K}^*| = |\mathbf{A}^*| \sin \beta.$$

Therefore,

$$\mathbf{S}^* = \mathbf{A}^* \cos \alpha - \frac{\mathbf{A}^* \cdot \mathbf{B}}{B^2} \mathbf{B} \cos \alpha$$

$$\mathbf{T}^* = \frac{\sin \alpha}{|\mathbf{B}|} \mathbf{B} \times \mathbf{A}^*$$

and

$$\mathbf{X}^* = \frac{\mathbf{A}^* \cdot \mathbf{B}}{B^2} \mathbf{B}(1 - \cos \alpha) + \mathbf{A}^* \cos \alpha + \frac{\sin \alpha}{|\mathbf{B}|} \mathbf{B} \times \mathbf{A}^*.$$

In terms of the indices h, k, l , the coordinates u_0, v_0, w_0 , fundamental reciprocal lattice vectors $\mathbf{a}^*, \mathbf{b}^*, \mathbf{c}^*$ and fundamental crystal lattice vectors $\mathbf{a}, \mathbf{b}, \mathbf{c}$,

$$\begin{aligned} \mathbf{A}^* &= h\mathbf{a}^* + k\mathbf{b}^* + l\mathbf{c}^* \\ \mathbf{B} &= u_0\mathbf{a} + v_0\mathbf{b} + w_0\mathbf{c} \\ \mathbf{A}^* \cdot \mathbf{B} &= hu_0 + kv_0 + lw_0 \\ B^2 &= u_0^2u_0^2 + v_0^2v_0^2 + w_0^2w_0^2 + 2u_0v_0\mathbf{a} \cdot \mathbf{b} + 2u_0w_0\mathbf{a} \cdot \mathbf{c} + 2v_0w_0\mathbf{b} \cdot \mathbf{c} \\ |\mathbf{B}| &= +\sqrt{B^2}. \end{aligned}$$

If the lattice is cubic

$$B^2 = (u_0^2 + v_0^2 + w_0^2)a_0^2$$

and the expression for \mathbf{X}^* may be written

$$\mathbf{X}^* = \frac{hu_0 + kv_0 + lw_0}{u_0^2 + v_0^2 + w_0^2} \frac{1}{a_0^2} (1 - \cos \alpha) \mathbf{B} + \mathbf{A}^* \cos \alpha + \frac{\sin \alpha}{\sqrt{u_0^2 + v_0^2 + w_0^2}} \frac{1}{a_0} \mathbf{B} \times \mathbf{A}^*.$$

Since in the cubic system every row of the crystal lattice is coincident with its corresponding row in the reciprocal lattice, u_0, v_0, w_0 may be replaced by h_0, k_0, l_0 , and \mathbf{B} by the reciprocal lattice vector $a_0^2 \mathbf{B}^*$. Then

$$\mathbf{X}^* = \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} (1 - \cos \alpha) \mathbf{B}^* + \mathbf{A}^* \cos \alpha + \frac{\sin \alpha}{\sqrt{h_0^2 + k_0^2 + l_0^2}} a_0 \mathbf{B}^* \times \mathbf{A}^*.$$

Again, only the direction of \mathbf{X}^* is of interest so that a_0^* (and also a_0) may be made equal to unity which eliminates the factor a_0 in the last term of \mathbf{X}^* , and

$$\mathbf{X}^* = \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} (1 - \cos \alpha) \mathbf{B}^* + \mathbf{A}^* \cos \alpha + \frac{\sin \alpha}{\sqrt{h_0^2 + k_0^2 + l_0^2}} \mathbf{B}^* \times \mathbf{A}^*.$$

in which the reciprocal lattice components of $\mathbf{A}^*, \mathbf{B}^*$, and \mathbf{X}^* are the corresponding indices. (This also holds only for the cubic case. The "indices" of \mathbf{X}^* are not necessarily integers.)

Written in terms of components along the axes of any Cartesian coordinate system, this expression for \mathbf{X}^* becomes

$$\begin{aligned} X_x^* &= \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} (1 - \cos \alpha) B_x^* + A_x^* \cos \alpha + \frac{\sin \alpha}{\sqrt{h_0^2 + k_0^2 + l_0^2}} (B_y^* A_z^* - B_z^* A_y^*) \\ X_y^* &= \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} (1 - \cos \alpha) B_y^* + A_y^* \cos \alpha + \frac{\sin \alpha}{\sqrt{h_0^2 + k_0^2 + l_0^2}} (B_z^* A_x^* - B_x^* A_z^*) \\ X_z^* &= \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} (1 - \cos \alpha) B_z^* + A_z^* \cos \alpha + \frac{\sin \alpha}{\sqrt{h_0^2 + k_0^2 + l_0^2}} (B_x^* A_y^* - B_y^* A_x^*) \end{aligned}$$

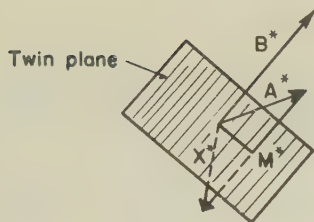


Figure 1

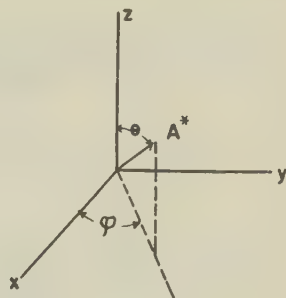


Figure 3

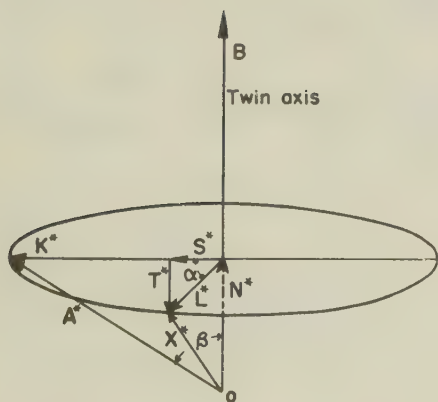


Figure 2

For the most common case of twinning by rotation, $\alpha = \pi$, and the formula for X^* reduces to

$$X^* = 2 \frac{A^* \cdot B}{B^2} B - A^*$$

or, for a cubic lattice,

$$X^* = 2 \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} B^* - A^*$$

and the Cartesian components are of the form

$$X_x^* = 2 \frac{hh_0 + kk_0 + ll_0}{h_0^2 + k_0^2 + l_0^2} B_x^* - A_x^*.$$

Twinning by Inversion Through a Lattice Point

Twinning by inversion through a point is merely a reversal of the sense of the reciprocal lattice vector. Therefore, if \mathbf{A}^* is the reciprocal lattice vector for the plane (hkl) and \mathbf{X}^* the reciprocal lattice vector for $(\overline{h}\overline{k}\overline{l})$,

$$\mathbf{X}^* = -\mathbf{A}^*$$

with Cartesian components of the form

$$X_z^* = -A_z^*.$$

Transformation Equations in Terms of Spherical Coordinates

Let the reciprocal lattice vector \mathbf{A}^* for the point (hkl) be located by θ and ϕ in some arbitrary Cartesian system xyz , as shown in Fig. 3. (For a grain in a rolled sheet, x may be the rolling direction, y the cross-rolling direction and z the normal to the rolling plane.) The following relations may be set up:

$$\begin{aligned}\mathbf{A}^* &= h\mathbf{a}^* + k\mathbf{b}^* + l\mathbf{c}^* \\ |\mathbf{A}^*| &= \sqrt{h^2a_0^{*2} + k^2b_0^{*2} + l^2c_0^{*2} + 2hka^* \cdot b^* + 2hla^* \cdot c^* + 2klb^* \cdot c^*} \\ &= \sqrt{A_x^{*2} + A_y^{*2} + A_z^{*2}} \\ A_x^* &= |\mathbf{A}^*| \sin \theta \cos \phi \\ A_y^* &= |\mathbf{A}^*| \sin \theta \sin \phi \\ A_z^* &= |\mathbf{A}^*| \cos \theta.\end{aligned}$$

Thus if hkl , and θ, ϕ are known, A_x^*, A_y^* and A_z^* may be found; also if A_x^*, A_y^* and A_z^* are known, θ and ϕ may be found.

For the cubic lattice the expression for $|\mathbf{A}^*|$ simplifies to

$$|\mathbf{A}^*| = \sqrt{h^2 + k^2 + l^2} a_0^*$$

and again if a_0^* is made unity

$$|\mathbf{A}^*| = \sqrt{h^2 + k^2 + l^2} = \sqrt{A_x^{*2} + A_y^{*2} + A_z^{*2}}.$$

Examples

I. Consider the case of twinning by reflection across the (112) plane of a cubic crystal. Let the orientation of the initial crystal be given by the full line gnomonic projection of the (hkl) net shown in Fig. 4.

The "indices," in terms of the initial lattice, of points on the lattice of the twin may be found by the formula

$$\mathbf{X}^* = \mathbf{A}^* - 2 \frac{h h_0 + k k_0 + l l_0}{h_0^2 + k_0^2 + l_0^2} \mathbf{B}^*$$

where the components of \mathbf{A}^* and \mathbf{B}^* are the reciprocal lattice components, i.e. the indices. Then, since $(h_0 k_0 l_0)$ is (112) ,

$$X_h^* = h - \frac{1}{3}(h + k + 2l)$$

$$X_k^* = k - \frac{1}{3}(h + k + 2l)$$

$$X_l^* = l - \frac{2}{3}(h + k + 2l).$$

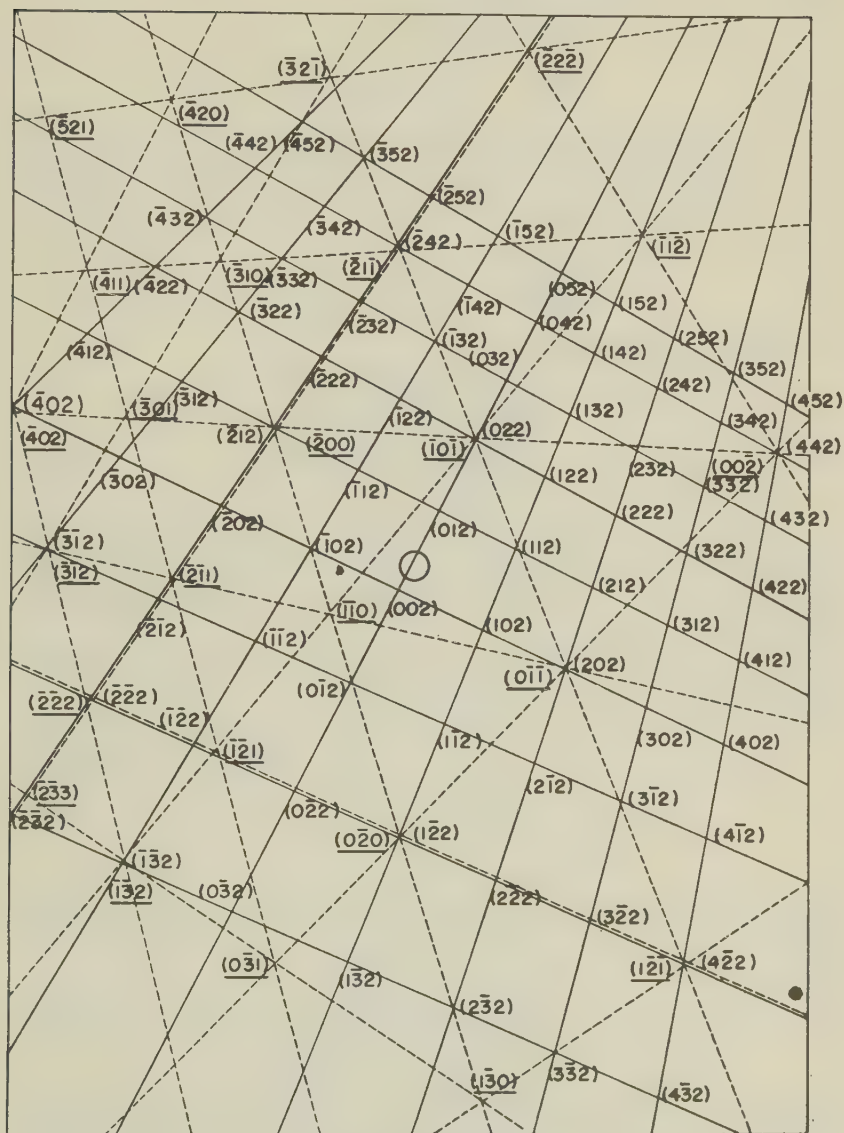


Figure 4

Using these relations, the twins (represented by X^*) of various planes (represented by A^*) may be found:

A^*	X^*
$(\bar{2}00)$	$\left(\frac{\bar{4}}{3} \quad \frac{2}{3} \quad \frac{4}{3} \right)$
$(0\bar{2}0)$	$\left(\frac{2}{3} \quad \frac{\bar{4}}{3} \quad \frac{4}{3} \right)$
$(00\bar{2})$	$\left(\frac{4}{3} \quad \frac{4}{3} \quad \frac{2}{3} \right)$
$(0\bar{1}1)$	$\left(1 \quad 0 \quad 1 \right)$
$(2\bar{2}2)$	$\left(2 \quad 2 \quad 2 \right)$

Therefore, on the projection

$(\bar{2}00)$ coincides with $(\bar{2}12)$

$(0\bar{2}0)$ coincides with $(1\bar{2}2)$

$(00\bar{2})$ coincides with (442)

$(0\bar{1}1)$ coincides with (202)

$(2\bar{2}2)$ coincides with $(\bar{2}22)$

From these points the gnomonic projection of the twin can be constructed, as shown by the broken lines in Fig. 4, which make up the (hkl) net with $h+k+l=-2$.

II. Consider the case of twinning by reflection across the $(10\cdot2)$ plane of a hexagonal crystal. In the hexagonal system

$$a_0^* = b_0^* = \frac{2}{\sqrt{3}a_0} \quad (\text{or } a_0 = b_0)$$

$$c_0^* = 1/c_0$$

$$a^* \cdot c^* = 0$$

$$b^* \cdot c^* = 0$$

$$a^* \cdot b^* = 1/2a_0^{*2}.$$

From these relations and the general formulas in the first section of this paper

$$A^* = ha^* + kb^* + lc^*$$

$$B^* = 1a^* + 0b^* + 2c^*$$

$$A^* \cdot B^* = ha_0^{*2} + 2lc_0^{*2} + \frac{1}{2}ka_0^{*2}$$

$$= \frac{2}{3a_0^2}(2h+k) + \frac{1}{c_0^2}2l$$

$$B^{*2} = a_0^{*2} + 4c_0^{*2}$$

$$= 4 \left(\frac{1}{3a_0^2} + \frac{1}{c_0^2} \right)$$

$$X^* = A^* - 2 \frac{A^* \cdot B^*}{B^{*2}} B^*.$$

Putting in the values found above for $A^* \cdot B^*$ and B^{*2}

$$X^* = A^* - \frac{(2h+k)\left(\frac{c}{a}\right)^2 + 3l}{\left(\frac{c}{a}\right)^2 + 3} B^*.$$

The "indices," in terms of the initial lattice, of points on the lattice of the twin may be found from the formula just derived by substituting the components of A^* and B^* along the reciprocal lattice axes, i.e. the indices:

$$\begin{aligned} X_h^* &= h - \frac{(2h+k)\left(\frac{c}{a}\right)^2 + 3l}{\left(\frac{c}{a}\right)^2 + 3} \\ X_k^* &= k \\ X_l^* &= l - 2 \frac{(2h+k)\left(\frac{c}{a}\right)^2 + 3l}{\left(\frac{c}{a}\right)^2 + 3}. \end{aligned}$$

III. The example just given may also be considered as a case of twinning by rotation of 180° about the row $(21 \cdot \bar{1})$. In the hexagonal system

$$\begin{aligned} a_0 &= b_0 \\ \mathbf{a} \cdot \mathbf{c} &= 0 \\ \mathbf{b} \cdot \mathbf{c} &= 0 \\ \mathbf{a} \cdot \mathbf{b} &= -\frac{1}{2}a_0^2. \end{aligned}$$

From these relations and the general formulas in the second section of this paper

$$\begin{aligned} A^* &= ha^* + kb^* + lc^* \\ B &= 2a + 1b + (-1)c \\ A^* \cdot B &= 2h + k - l \\ B^2 &= 4a_0^2 + b_0^2 + c_0^2 - 2a_0^2 \\ &= 3a_0^2 + c_0^2 \\ X^* &= 2 \frac{A^* \cdot B}{B^2} B - A^* \end{aligned}$$

or, putting in the values found for $A^* \cdot B$ and B^2

$$X^* = 2 \frac{2h+k-l}{3a_0^2 + c_0^2} B - A^*$$

The "indices," in terms of the initial lattice, of points on the lattice of the twin may be found from this formula by substituting the components of A^* and B along the reciprocal lattice axes. For A^* these will be the indices, but an expression must be found for B in terms of a^* , b^* , c^* instead of a , b , c . In the hexagonal system

$$a = a_0^2 a^* - \frac{1}{2} a_0^2 b^*$$

$$b = -\frac{1}{2} a_0^2 a^* + a_0^2 b^*$$

$$c = c_0^2 c^*.$$

Therefore

$$B = \frac{3}{2} a_0^2 a^* - c_0^2 c^*$$

and

$$\begin{aligned} X_h^* &= 3 \frac{2h + k - l}{3 + \left(\frac{c}{a}\right)^2} - h \\ X_k^* &= -k \\ X_l^* &= -2 \frac{(2h + k - l) \left(\frac{c}{a}\right)^2}{3 + \left(\frac{c}{a}\right)^2} - 1. \end{aligned}$$

These "indices" are not identical with those of example I, but may be derived from them by symmetry operations of the lattice.

The author wishes to express her deep appreciation to Dr. David Harker for his thorough consideration of this work, and many helpful suggestions both as to form and contents.

NOTES AND NEWS

ON THE ADSORPTION OF SOME ORGANIC DYES BY CLAYS AND CLAY MINERALS

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In recent years this subject has been investigated from various points of view. In an attempt to discover fundamental laws governing some of the anomalies, I have been concerned mainly with the quantitative aspect and microscopic examination. German investigators before the war tried to correlate the adsorption of malachite green, for example, with oil decolorization. My work has been confined to reactions between identified specimens, and wherever possible to clay minerals, and a limited number of organic compounds. This is absolutely necessary in a study of this character as even the purest type of clay, kaolin, always consists of at least two minerals, namely quartz and kaolinite. Bentonites, at least those examined, have a glassy phase present in varying amounts. More often than not limonite, hematite, feldspars, and hydromicas are present as well in kaolins, etc. X-ray determinations by Dr. R. E. Grim have shown the presence in South African fireclays of montmorillonite. Usually regarded as almost solely composed of kaolinite as the clay mineral and as tests of the benzidine reaction are of little value in this case, more discriminating work is necessary. In South African soils the swelling types of montmorillonite, and especially illite, are far commoner than generally suspected. This is very important from the soil mechanics point of view.

A microscopic examination of the coarser separates from a mechanical analysis often shows that the adsorption is not uniform on the grains. When dealing therefore with such complex reactions one must build on a sound foundation. The results of Hauser and Leggett (1), for example, cannot in my opinion be widely accepted because the clays used in their investigations are not specified in any way.

A. Quantitative Determinations

In Table 1 the chemical analyses of two rocks are given. The Wyoming bentonite is an identified sample, the rough analysis showing it to have a similar composition to the one quoted later in this paper. Any one familiar with the chemical composition of clays is aware of the care that must be exercised when describing these rocks as "a dried sample." A considerable amount of water is driven off from temperatures of 105°C. upwards and it is very difficult to draw a sharp distinction between moisture and combined water, especially in the case of montmorillonite-bearing clays. A sample dried at temperatures of 105° to 110°C. has still a considerable amount of water present which may take part in the reactions Hauser and Leggett investigated.

TABLE 1

	1.	2.
SiO ₂	44.40	46.38
Al ₂ O ₃	38.10	36.58
Fe ₂ O ₃	3.80	0.88
TiO ₂	0.09	0.31
CaO	0.06	0.60
MgO	tr.	0.49
Na ₂ O	—	0.04
K ₂ O	—	0.88
Loss on Ignition	12.85	12.22
H ₂ O	—	0.67
	99.30	99.05

1. Kaolin, White River, Transvaal. *Analyst V. L. B.*

2. Purified kaolin supplied by Wengers Ltd., Stoke-on-Trent. *Analyst V. L. B.*

Working with the dyes malachite green, congo red and methyl violet, the adsorptive powers were tested on these two clays as well as on the bentonite. Aqueous solutions were used throughout with a concentration of 0.025%. Previously (2) I had shown that in two hours contact over 90% of the dye was adsorbed. In these experiments at least 24 hours contact was allowed to ensure "satisfaction" of the clay's adsorption powers. In Table 2 the results are summarized.

TABLE 2

Clay Type	Amount of dye adsorbed in gms. per gram of clay		
	Malachite green	Congo red	Methyl violet
Kaolin, Stoke-on-Trent	.0074	.0081	.0083
Kaolin, Natal	.0068	not det.	not det.
Kaolin, Transvaal	.0082	.0073	.0083
Bentonite, Wyoming	.036	.045	.047
Montmorillonite-rich fraction, S. African clay. Potchefstroom.	.050	not det.	not det.

Bearing in mind that the samples are not pure, the inference can be made from these results and for these samples at least, that the amount of dye adsorbed is dependent upon the clay type, that is, it is a function of its chemical and mineralogical composition. The grain size appears to be of little importance.

No difficulty was experienced in getting clear filtrates except in the case of the Stoke-on-Trent kaolin which had been stained by Congo red. In this case several layers of the finest Whatmans No. 542 paper proved satisfactory.

The results indicate that there is a limiting value for each clay type. If this can be shown to apply generally then such quantitative determinations may be of considerable value in the study of clays and soils.

B. Qualitative Determinations

In this part of the research only analyzed specimens were used for the critical work. In a few cases to complete the tables and only where negative color reactions were obtained, specimens which had not been analyzed were used. All these tests were carried out on small quantities, that is spot tests. Frequent examinations under the microscope were made in order to observe if it was a "whole hearted" reaction and not a portion of the rock which was giving the color change. Owing to the difficulty of obtaining the reagents only a few compounds were used to continue the work of Hauser and Leggett. The illite and montmorillonite specimens were obtained from Dr. R. E. Grim of the Illinois Geological Survey. The amounts of these were too small to permit quantitative determinations.

The qualitative work can be divided into two parts:—

(1) The use of naturally colored dyes as malachite green, methyl violet, congo red, fuchsin basic, etc. All the clays examined in the course of a survey of the Union of South Africa and amounting to about four or five hundred samples, adsorbed these compounds in varying amounts. Note that the color is stable on drying.

(2) The use of colorless or only slightly colored amines as *o*-toluidine, benzidine, diphenylamine, aminoazobenzene, etc. Only the montmorillonite or illite-bearing specimens reacted. The colors fade or disappear altogether on drying. (See Tables 3A, 3B, and 4.)

TABLE 3A

Specimen	Natural Color	pH	Group 1 Reagents			Group 2 Reagents		
			Malachite green	Congo red	Methyl violet	Benzidine	<i>o</i> -Toluidine	Diphenyl-amine
Kaolinite, Middleburg, Transvaal	White	7.0	+	+	+	— Wet or	— dry no rea	— ctions.
Kaolin, White River	White	6.0	+	+	+	—	—	—
Kaolin, Stoke-on-Trent	White	7.0	+	+	+	—	—	—
Fireclay, Glenboig	Lead gray	7.0	+	not det.	not det.	—	—	—
43-2 μ Fraction of Kaolin	White	not det.	+	+	+	—	—	—

VOLUMETRIC COMPOSITION

Kaolinite	82.7
Quartz	5.7
Muscovite with some biotite	11.4
Iron oxides	0.1
Feldspars	tr.
	99.9

CHEMICAL ANALYSIS

SiO ₂	50.3
Al ₂ O ₃	32.0
Fe ₂ O ₃	
Loss on ignition	11.1
	93.4

Assuming the remainder of this analysis as K₂O and recalculating on this basis gives a surplus of 6.6% free silica, thus corresponding well with the micro-metric value of 5.7%.

Analyst V.L.B.

The grains in this specimen when examined under the microscope exhibit "zoning" due to adsorption of the dyes.

TABLE 3B

Specimen	Natural color	pH	Group 1 Reagents			Group 2 Reagents		
			Malachite green	Congo red	Methyl violet	Benzidine	<i>o</i> -Toluidine	Diphenyl-amine
Illite, Illinois	Dirty shale	7.0	+	+	+	Prussian blue	Dirty green, not distinct	—
Illite, Goose Lake	Dirty shale	7-8	+	+	+	Prussian blue	Dirty green	—
Bentonite, Wyoming	Dirty white	7-8	+	+	+	Prussian blue, deep.	—	—
Montmorillonite, Wyoming	Pale buff	7-8	+	+	+	Deep prussian blue.	—	—
Activated fuller's earth	Dark buff	>4.0	+	not det.	not det.	—	Brownish Color?	Dirty green
		>8.0				—	not det.	not det.

Note. In all these tests using group 2 reagents the materials were mixed dry (at 110°C.). In no case could any reaction be seen. On wetting the reaction proceeded in the case of benzidine. The observations on fuller's earth are incomplete, but the reactions appear to be similar to the rocks predominantly composed of kaolinite.

TABLE 4

Specimen	Benzidine	Aminoazobenzine	Nitrophenol
Natrolite from Berg basalt, Natal. Dept. N. U. C. no. 528	Dry, nil Wet, nil	No discernible reactions, wet or dry	No reaction discernible
Kaolin Ndedwe from N. U. C.	Dry, nil	No discernible reactions	No reaction discernible
Zeolite (?), S.W. Africa. Natal Museum no. 1671	Dry, nil Wet, nil	No discernible reactions	No discernible reactions
Bentonite, Wyoming, obtained from Dr. F. C. Tompkins	Dry, nil Wet, deep prussian blue	No discernible reactions	Intense canary yellow coloration, different from the color of the nitro- phenol

The glassy material in the bentonite shows no reaction at all with any of these reagents.

A study of these results shows three important facts.

(1) All the clay minerals adsorb the dyes of group 1 listed above, in varying amounts. The dye once taken up by the clay mineral is relatively fixed. The color however can be changed by varying the pH .

(2) The color reaction of benzidine appears to be confined to illite and montmorillonite. Kaolinite at any rate does not show any color reaction. This is very important as Page (4) has doubted the validity of the benzidine test for montmorillonite in soils advocated by Hendricks and Alexander (5).

(3) The *o*-toluidine reactions are not as distinctive as the benzidine ones.

Since completing this work, I carried out some additional tests at Natal University College at Pietermaritzburg. Working on a bentonite from Wyoming, I obtained further interesting results. I am indebted to Dr. F. C. Tompkins of the Department of Chemistry for the specimen and also for the following analysis:—

SiO ₂	61.78
Fe ₂ O ₃	3.10
FeO	0.28
MnO	0.08
Al ₂ O ₃	21.56
CaO	0.68
MgO	2.62
K ₂ O	0.31
Na ₂ O	2.22
SO ₃	tr.
H ₂ O (110°C.)	3.10
Ignition loss	4.73

100.46

S.G.

2.0

Analyst unknown.

This sample of bentonite, composed mainly of montmorillonite, but also containing small proportions of a glassy phase, reacted with benzidine in the normal manner. The glassy phase under the microscope showed no change in color after the benzidine had been added. Substituting ethyl alcohol for water, no color reaction was noted. Upon the addition of water the color developed immediately. The color reaction, therefore, depends upon ionization and can only take place in the presence of water which is not combined in the clay mineral complex. Dr. F. C. Tompkins pointed out the resemblance between this and the iodine coloration of starch in the presence of potassium iodide. I tried out dilute solutions of iodine in potassium iodide aqueous solutions and found that the blue color was destroyed on drying, but returned on wetting again. This process could be repeated a number of times. It would appear that these phenomena are of the same kind.

With regard to Page's criticism of the test of benzidine for montmorillonite, I would point out that many of the kaolins examined contained over 0.5% ferric oxide and the Transvaal one nearly 4%. The activated fuller's earth besides being very acid contains appreciable quantities of ferric oxide. Page emphasizes the part played by Fe^{+++} in the production of color and postulates that this phenomenon may be due entirely to the ferric ion and not to the clay mineral at all. My results show that even in the presence of appreciable quantities of ferrous and ferric oxides, in the case of kaolins, no color reaction takes place.

Dr. L. C. King of the Department of Geology, Natal University College, placed at my disposal several specimens of zeolites. Although these have not been critically determined, as the results were negative, I have included them to indicate the direction of the work. While it would appear that the zeolites are not very reactive, more detailed work is necessary before any conclusions can be made. The same applies to pyrophyllite.

C. Conclusions

From these experiments it would appear that the two types of reactions, although probably of the same kind, are different in their outward results.

(1) The stains are fixed in the mineral constitution. The reaction is apparently irreversible.

(2) Color reactions which may be due to resonance set up by various ions and the organic compound. "Removal" of the water destroys the color, addition of it restores it.

Acknowledgments

I am indebted to Drs. L. C. King, F. C. Tompkins, Lawrence, and R. E. Grim for specimens.

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METHOD FOR ELEVATING LOW UNIVERSAL STAGE FLOOR-PLATE

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Efficient universal stage operation requires that the central plane of the thin-slice itself must lie, or be brought to lie, in the plane defined by the horizontal axes of the instrument. The thickness of object-glasses and cover-glasses used by different thin-section preparators, both here and abroad, often varies considerably. To allow for this lack of uniformity most stages are equipped with some device for adjusting the height of the glass floor-plate carrying the thin section; thus providing accommodation for use with sections of widely different types.

In the 5-circle Bausch and Lomb universal stage (Emmon's model), vertical adjustment of the section is accomplished by rotation of a finely threaded ring on the under side of the stage. In the particular instrument used by the writer this ring cannot be raised sufficiently high to elevate adequately the thin sections obtained, despite the fact that the latter are procured from an experienced manufacturer (object-glass thickness circa 1.0 mm., coverglass thickness circa 0.13 mm.). In consequence of this deficiency the image of even a most accurately centered grain plunged rapidly away (northward) from the cross-hair intersection when the instrument was rotated about the E-W control axis away from the observer. This indicated that the section was still too low although the floor-plate was adjusted to its maximum height. Such behavior creates visual confusion, uncertainty in precise determination of extinction position, and soon induces oppressive eyestrain if the instrument is used continuously for any appreciable time.

Whether such a defect is a peculiarity of this instrument alone, merely inadvertent, or typical of all stages of such type, is not known. In any case, with continued absence of thin-section standardization it may be anticipated that similar difficulties will be encountered by others. Hence, a brief description of a simple means of correction of stages with insufficient vertical adjustment seems pertinent.

If the section cannot be elevated sufficiently to bring it precisely into the plane of the horizontal axes there are, in general, two possibilities, short of actual modification of the stage, for correcting this condition. Either (1) a means must be found to increase the thickness of the thin section object-glass, or (2) an exceedingly low platform may be erected on the working face of the glass floor-plate itself. No matter which method is adopted application of one or more large cover-glasses cemented firmly

with Canada balsam very probably will suffice to obtain the necessary elevation.

If the thickness of a thin section be increased by cementing a cover-glass directly to its under side, care must be taken to prevent overheating of the preparation when the balsam is applied. Such precautions as are necessary to prevent slipping or fragmentation of the rock-slice are especially important when oriented sections are used as in petrofabric studies. Also, when the section itself is modified the cover-glass applied to the lower surface must be sufficiently large so that there will be no tendency for the slide to tilt when moved about into positions remote from the center of the stage.

For a more permanent correction it is recommended that a single large (30×50 mm.) cover-glass, or two smaller ones (22×30 mm.) placed side by side, be cemented directly to the glass floor-plate supporting the thin section. This arrangement is more generally satisfactory since correction need only be made once provided the same type of thin sections are used subsequently. Moreover, the above-mentioned danger of injury from overheating of sections is obviated.

To prevent development of air bubbles beneath the cover-glasses balsam in xylene may be used. The floor-plate and cover-glass assembly should be heated very slowly at low temperatures, until sufficient volatile matter is driven off so that the balsam becomes hard on cooling. With this procedure care must be taken not to apply so much heat that strains develop in the floor-plate glass or its metal mount, and the whole unit must be slowly cooled. As a precaution the assembly may be tested for strain with a Berek compensator after cementing is complete.

Interposition of thin plates like cover-glasses between the thin section and glass floor-plate does not, in the usual case of routine measurements, cause sufficient deviation in the direction of measured optical vectors as to necessitate their angular correction before plotting.

NATIONAL SECTION OF PAIMEG

United States Section of the Pan American Institute of Mining Engineering and Geology has been formed and is now open for charter members.

The First Pan American Congress of Mining Engineering and Geology, organized and directed by the Institute of Mining Engineering of Chile and officially authorized by the Government of Chile and the South American Union of Engineering Associations, was held in Santiago, Chile, January 15 to 23, 1942. The A.I.M.E. appointed several delegates to this Congress including Edward Steidle and Will Wright. Mr. Wright was selected to head the group and prepared the report on the meetings which was published in *Mining and Metallurgy* of March, 1942. The United States Government appointed D. F. Hewett to represent the Geological Survey, Elmer Pehrson the Bureau of Mines, and Will Wright the State Department. Edward Steidle represented the Commonwealth of Pennsylvania.

At this Congress it was decided to organize a Pan American Institute of Mining Engineering and Geology (PAIMEG) with headquarters in Santiago, Chile. National sections have been organized in Argentina, Bolivia, Brazil, Chile, Peru and Uruguay. This organization naturally wanted the support of A.I.M.E. and at the February meeting, 1943, at a meeting of the Board, Mr. Albala, the General Secretary of PAIMEG, discussed the object of the organization and their desire for our support.

The first Congress embraced 14 sections, representing every branch of the mineral industries. Perhaps the most important result of the Congress was the mutual recognition by the representatives of all nations that the Americas face a common problem of defense in the present emergency and possibly even more serious social and economic readjustments in the post-war years. Therefore, recommendations were made by resolution of the Congress with the intention of establishing good-neighbor policies with respect to minerals on a firm basis.

PAIMEG desires to cooperate with all the mineral industries societies of the Americas, support all activities that will benefit the mineral industries, and expand fundamental knowledge of geological conditions and encourage the standardization of technical terminology. The Institute will also facilitate the interchange of publications, students, professional men, and industrialists connected with the mineral industries.

PAIMEG is proposed as an autonomous private institution independent of the governments of the Americas. Qualified candidates from commercial organizations, societies, universities, et cetera, which are closely related to the mineral industries are accepted as members. PAIMEG wishes to organize through the initiative of individuals and private interests without having the necessity, for the time being, of asking help of the governments concerned.

At the annual A.I.M.E. meeting last February Mr. Wright met with President Mathewson, Secretary Parsons, Edward Steidle and D. F. Hewett and discussed the possibilities of organizing a national section of PAIMEG in the United States. At Mr. Parsons' suggestion, it was decided to hold an initial meeting in New York on April 19, at the time of the regular A.I.M.E. Board meeting. Edward Steidle served as Chairman of the "steering committee" in accordance with a request from President Rodriguez, PAIMEG, under date of November 10, 1943. A second Congress is scheduled to be held in Rio de Janeiro, Brazil, in October 1944, but will no doubt be postponed for the duration. Future Congresses will be sponsored by PAIMEG.

Chairman Steidle invited 70 men, principally of New York and Washington, who have had some personal contact with the Latin Americas, to attend a steering committee meeting in New York on April 17. He received 43 acknowledgments of which 38 offered to join immediately. Seven additional men sent word indirectly that they would join.

The consensus of the steering committee was that it was most desirable that a National Section of PAIMEG be formed in the United States without further delay. A motion establishing the Section carried unanimously. Upon proper nomination and vote, the following were elected as a National Directorate:

CHAIRMAN: Edward Steidle, Dean, School of Mineral Industries, The Pennsylvania State College.

VICE-CHAIRMAN: C. W. Wright, Chief Foreign Minerals Specialist, United States Bureau of Mines.

SEC'Y-TREAS: A. T. Ward, Mining Engineer, New York City.

DIRECTORS: D. F. Hewett, In Charge, Section of Metalliferous Deposits, United States Bureau of Mines.

M. B. Gentry, Vice President, Freeport Sulphur Company, New York City.

T. T. Read, School of Mines, Columbia University.

W. E. Milligan, Department of Metallurgy, Yale University.

Members of any mineral industries society in the United States and Canada are eligible to join the National Section. Individuals paying 1944 dues, amounting to five dollars (no initiation fee) before December 31, 1944, will be recorded as Charter Members. The Chairman was requested to make this known to interested people through the medium of the various publications in the field of the mineral industries, including societies and other technical organizations. At this stage, membership must be based on willingness to aid in fostering good will and better understanding among mineral industries engineers and technologists in the Western Hemisphere. Anyone interested in joining PAIMEG as a charter member is requested to forward dues to Edward Steidle, Chairman, National Directorate, PAIMEG, State College, Pennsylvania, or to Arthur T. Ward, Secretary-Treasurer, National Directorate, PAIMEG, 50 Church Street, New York City. Minutes of the organization meeting will be forwarded to all members.

PROCEEDINGS OF SOCIETIES

ABSTRACTS OF MINUTES OF THE NEW YORK MINERALOGICAL CLUB

Meeting of November 17

Mr. James G. Manchester presented to the club a book of photographs recording the early activities of the club. Dr. William A. Mudge of the International Nickel Company spoke briefly on the early history of the nickel industry and presented a sound film of the mining and processing of nickel and copper by his company.

Meeting of December 15

Mr. Jay T. Fox addressed the meeting on "Photographing Your Minerals in Color," illustrating the lecture with his own excellent color slides. The advantage of a dye film over a grain film (black and white) for giant enlargements was explained and the necessity for precision of exposure time and rigidity of equipment was emphasized.

Meeting of January 19

The president, Mr. Taylor, announced the death of Mr. George L. English on January 2 at Winter Park, Florida. Various members paid tribute to Mr. English, describing his interest in rare earth minerals and the important part he played in the assembling of many of the mineral collections of his day. Dr. Clifford Frondel spoke on "Mineralogical and Industrial Aspects of Twinning," illustrating his lecture with photographs of various twins of common minerals and discussing the part that twinning in quartz plays in the manufacture of quartz oscillator plates for radio transmission.

Meeting of February 16

Mr. Ernest Weidhaas, long a member of the club, spoke on "Freak Simulations in Minerals." He gave a historical sketch of the early uses of such simulations as amulets and talismans and told of his own experiences in accumulating his extensive collection. Specimens from this collection displayed by Mr. Weidhaas included simulations of fruit, animals, and famous people.

Meeting of March 15

Mr. Ralph J. Holmes of the teaching staff of Columbia University addressed the meeting on "X-Ray Diffraction in its Role in Modern Mineral Study." He gave a brief and lucid description of the various techniques of x -ray diffraction research and showed the instruments involved in each. Drawing examples from his own research, Mr. Holmes described problems whose solution had depended chiefly on x -rays, but emphasized the advisability of using all available techniques in solving the problems of crystal structure analysis. The attendance at the meeting was the maximum for the present year.

ELIZABETH ARMSTRONG, *Secretary*

BOOK REVIEW

MINERAL RESOURCES OF MINNESOTA, Bulletin 30, 1943, University of Minnesota and the Minnesota Geological Survey. Edited by WILLIAM H. EMMONS and FRANK F. GROUT. Sections prepared by Frank F. Grout, John W. Gruner, George M. Schwartz, Clinton R. Stauffer, and George A. Thiel.

The above bulletin contains 149 pages and 25 figures. It is a résumé of the mineral resources of Minnesota, and is introduced by a brief discussion of the physiography and general geology of the State in order to furnish a background for a discussion of the mineral deposits. Since iron ore is Minnesota's most important mineral resource it receives the most attention. Not only is the geology of the iron deposits outlined, but the problems resulting from the exhaustion of the high-grade ore in the next 30 or 40 years, and the utilization of the low-grade ores are discussed.

The other mineral resources reviewed, in approximately their order of importance, are building stones, sand and gravel, clays and shales, limestones and marls, broken and crushed rock other than limestone, peat, miscellaneous non-metallic minerals including water resources, and miscellaneous deposits of metals.

An appendix includes minerals of interest to collectors, a list of minerals of Minnesota, a list of publications of the Geological Survey of Minnesota, and a selected list of other papers on the mineral resources of the state.

The bulletin is prepared so as to be especially helpful to those who are developing and producing the mineral resources of the State, and to those engaged in their conservation and political economics.

A. J. EARDLEY, *University of Michigan*

NEW MINERAL NAMES

Hydrogrossular

C. OSBORNE HUTTON: Hydrogrossular, a new mineral of the garnet-hydrogarnet series. *Trans. Proc. Royal Soc. New Zealand*, 73, 714-180 (1943).

The name hydrogrossular is proposed for all of the isomorphous mixtures between hibschite ($3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) and grossularite. An analysis is given of such material with $n = 1.7021$ and $G. = 3.35$, separated from rodingite rock, Dun Mt. Optical data and gravity determinations are given for other occurrences.

DISCUSSION. The series $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2 - 3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{H}_2\text{O}$ has been prepared, but no natural material has yet been reported more hydrous than hibschite. It seems likely that many "grossularites" will be found to be actually hydrous minerals of this series. There are too many names already for the series—hibschite, plazolite, hydrogarnet, garnetoid, grossularoid and hydrogrossular. Hibschite has priority over plazolite and the latter name should be dropped. Hydrogarnet and grossularoid are ambiguous terms. Garnetoid is a term including minerals other than those of this series.

MICHAEL FLEISCHER

Alpha-vredenburgite, beta-vredenburgite

BRIAN MASON: Alpha-vredenburgite. *Geol. För. Förh.* (Stockholm) 65, 263-270 (1943).

Vredenburgite was redefined in a previous paper (see *Am. Mineral*, 29, 73-74 (1944) as intergrowths of cubic and tetragonal $(\text{Mn}, \text{Fe})_3\text{O}_4$ in the composition range 54-91% Mn_3O_4 . The present paper describes homogeneous tetragonal $(\text{Mn}, \text{Fe})_3\text{O}_4$ from Långban, Sweden, containing 65-76% Mn_3O_4 , probably formed by the reduction of bixbyite at low

temperatures. It is suggested that this homogeneous material be called alpha-vredenburgite and the mixture of cubic and tetragonal $(\text{Mn, Fe})_3\text{O}_4$ be called beta-vredenburgite.

DISCUSSION: The proposed nomenclature is likely to cause confusion. It would be simpler to refer to the homogeneous tetragonal mineral as iron-bearing hausmannite and to restrict the term vredenburgite to the mixture, as in the earlier paper.

M. F.

Endellite

L. T. ALEXANDER, G. T. FAUST, S. B. HENDRICKS, H. INSLEY AND H. F. McMURDIE. *Am. Mineral.* **28**, 1-18 (1943).

Gamagarite

J. E. DEVILLIERS. *Am. Mineral.* **28**, 329-335 (1943).

Partridgeite

J. E. DEVILLIERS. *Am. Mineral.*, **28**, 336-338 (1943).

Sillenite

CLIFFORD FRONDEL. *Am. Mineral.*, **28**, 521-535 (1943).

Beyerite

CLIFFORD FRONDEL. *Am. Mineral.*, **28**, 521-535 (1943).

REDEFINITION OF SPECIES

Parkerite

C. E. MICHENER AND M. A. PEACOCK. *Am. Mineral.*, **28**, 343-355 (1943).

Bismite

CLIFFORD FRONDEL. *Am. Mineral.*, **28**, 521-535 (1943).

NOTICE TO USERS OF G.S.A. MEMOIR 8

Available on request at the G.S.A. headquarters is a copy of Plate 9 for Memoir 8 on a reduced scale to fit Plate 12. It was the original intention to reproduce Plate 12 with new data on the scale of Plate 9 but current conditions prevented. The new Plate 9 is offered for temporary use until the new data for Plate 12 are made available.

Frank C. Schrader, retired member of the U. S. Geological Survey, died April 16, at the age of eighty-three.

George Steiger who joined the U. S. Geological Survey in 1892 and was chief chemist from 1916 to 1930, died April 18. He was seventy-four years old.

Dr. Roger Clark Wells who succeeded Mr. Steiger as chief chemist of the U. S. Geological Survey in 1930, died April 19, at the age of sixty-six.

Due to increased demands on his time in connection with departmental matters, Professor Paul F. Kerr has found it necessary to resign as Secretary of The Mineralogical Society of America, a position he has held since 1934. The Council has selected Professor C. S. Hurlbut, Jr., of Harvard University to serve as Secretary. As in the past the annual election of all officers of the Society for 1945 will be held in December.